PARI

2012

PARI Summer Student Proceedings

PISGAH
ASTRONOMICAL
RESEARCH
INSTITUTE

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PARI SUMMER STUDENT RESEARCH PROCEEDINGS

The 2012 Summer Research Students at PARI experienced a rich set of special guest lectures by world-renowned scientists, conducted research, learned new research skills, and presented their research results. Fifty four resident high school students conducted research ranging from Earth's climate to supernova remnants. Undergraduates residing at PARI enjoyed research challenges that included observing near earth asteroids, installing a calibration source on the PARI Smiley 4.6-m radio telescope, writing the control software for the new PARI geomagnetometer, developing kiosk multimedia software, upgrading the Smiley radio telescope control software for new technology, re-defining the pointing models of the 26-m radio telescopes, development of radio receivers that will combine the power of the two 26-m radio telescopes into a single telescope, and working with the PARI education team with internet infrastructure and by being instructors and mentors for our high school scholars. Students and their mentors and instructors were all enriched by the broad range of research and education experiences! We want to share the summer student research papers in these proceedings. The student research papers in the proceedings are:

Duke TIP – 30 high school students engaged in astronomical research
Climate and Space Science Workshop – 24 homeschool high school students engaged in climatic studies
Space Science Lab Workshops
J. Donald Cline Space Grant Scholar – Emma Taylor, Guilford College
Edward Douglas "Chip" Parks Intern – Menelik Zafir, Georgia State University
Digital Resources and Science Education Intern – Rebekah David, UNC-Asheville
EMC Corporation Intern – Matthew Grimes, UNC-Asheville
WCU Senior Capstone Project - Veronica Flamenco, Joshua White, and Josh Williams
PARI Science Education Intern - David Weigel, Furman University
PARI Science Education Fellow - Lee Craig, York Technical College
Furman Scholars – Robert Picardi and Lawson Smith, Furman University
PARSEC Interns – Joe Peters, UNC-Asheville

We want to thank all of the summer 2012 students for sharing their enthusiasm to learn. We enjoyed our eleventh year with the Duke TIP Summer Field Studies for high school students at PARI. We send a special thanks to Dr. Nicki Charles, TIP Program Director, and TIP group leader at PARI, Annie Bartels. We thank all of our Teaching Assistants this summer including Stephen Hawk, David Weigel, Meagan Green, Bethany Woodman, and Elias Mohr. Our summer programs challenge our network and internet infrastructure and so we are indebted to Bob Hawkins Ashley Perdue, Jessica Anderson and EMC Corporation for their IT and intern support of our summer programs. Thurburn Barker, Director of the Astronomical Photographic Data Archive provided his expertise and mentorship of our students and we are grateful for his continued dedication. We thank Don Cline, John Sinclair, Dr. John Meriwether, Dr. Brian Dennison, Dr. David Moffett, and Rodney Keaton for their research seminars presented to the TIP students. We thank Drs. Brian Dennison, Chuck Bennett, and David Moffett from PARSEC for the continued research collaboration and giving their students the research experience at PARI. In particular, we greatly appreciate Dr. Stephanie Brown-Houston, NASA Education Program Specialist, for her support of the PARSEC-PARI collaboration. We are very grateful to Janet Parks and thank her for the scholarship opportunity she provided to our intern this summer. We thank the PARI staff for their unrelenting support to assure the programs run smoothly. Jo and Don Cline are two very special people whose vision we share for student enrichment in science, technology, engineering, and mathematics. We are deeply thankful for their many contributions and involvement in making the programs at PARI successful. Thanks Jo and Don!

Michael Castelaz, Ph.D.
Science Director

Christi Whitworth
Education Director

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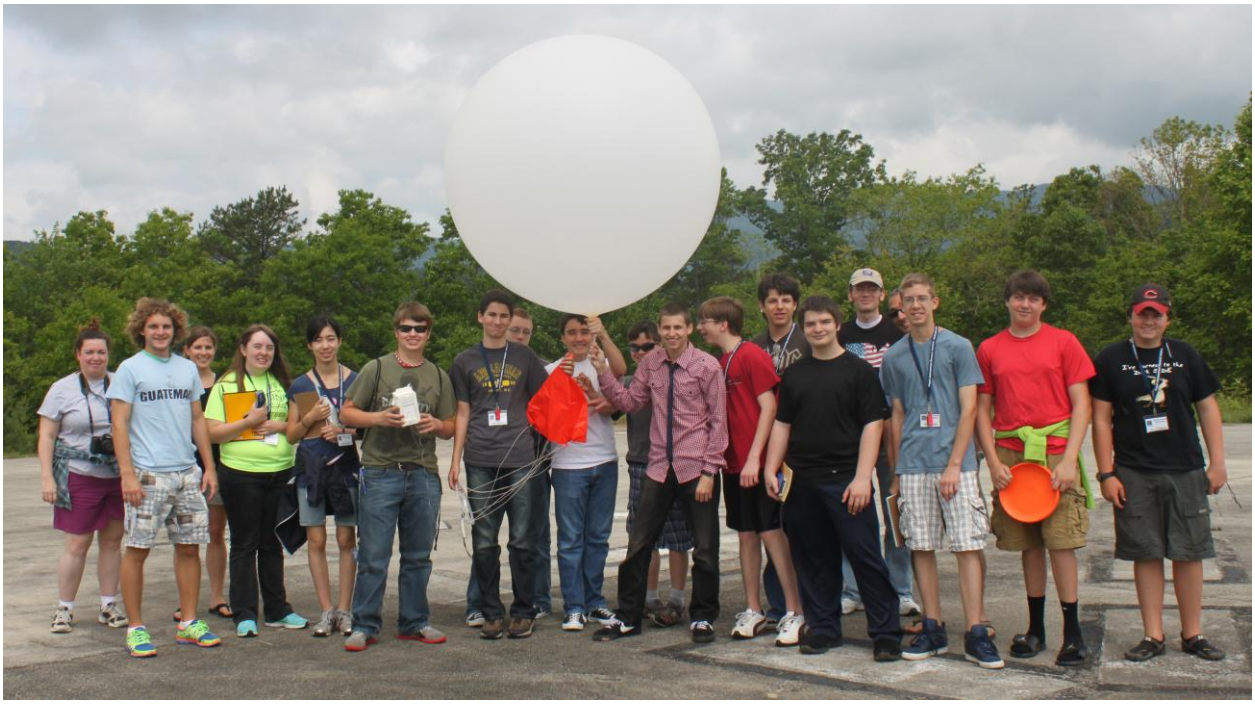
PARI / APPALACHIAN STATE UNIVERSITY HOMESCHOOL CLIMATE AND SPACE SCIENCE CAMP

May 20-25, 2012

PARI-Appalachian State University Climate and Space Science Camp



Funded through the Climate Action Network through Direct Observations and Outreach (CAN-DOO): Promoting Climate Science Awareness through Public Outreach, STEM Education, and Citizen Science grant awarded by NASA brought twenty-four homeschooled North Carolina students (ages 14-17) to participate in the one-week camp held at PARI. The camp consisted space science, taught by PARI scientists and three days of climate science, taught by CAN-DOO project scientists.

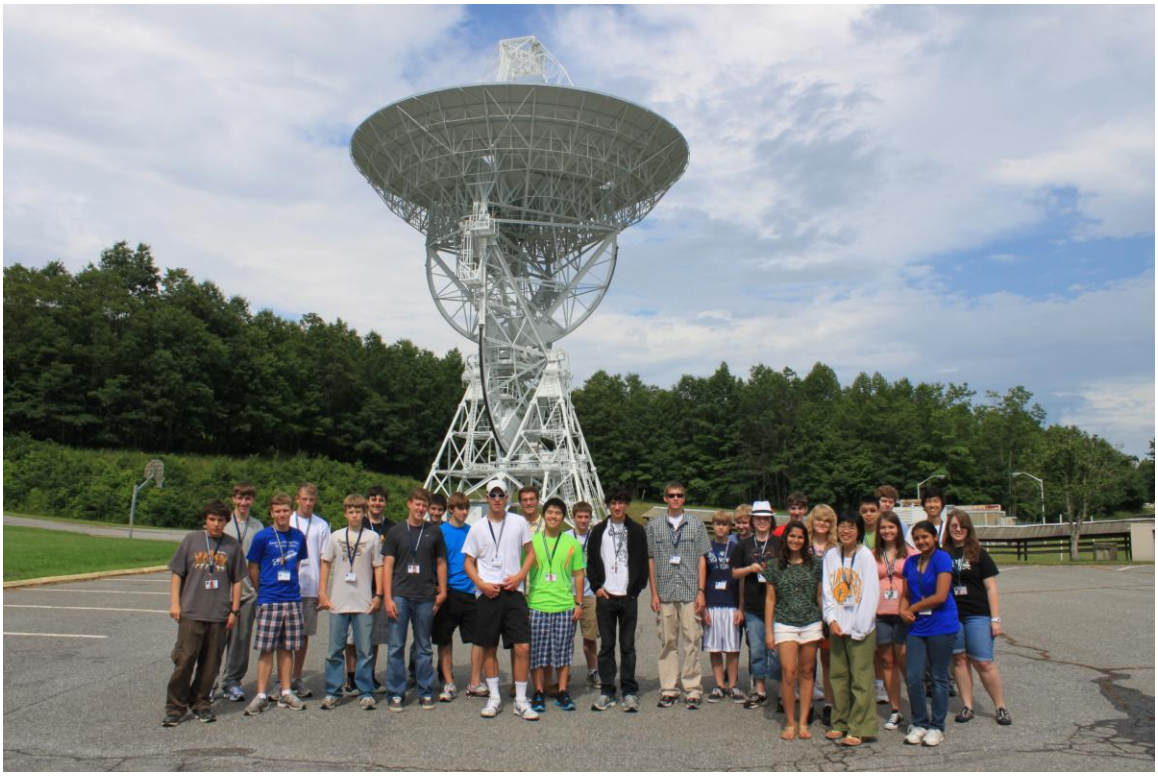
Activities included an introduction to meteorology and climate science and learning to take solar irradiance measurements using a solar pyranometer that the students calibrated. Students were also exposed to IR temperature sensing and cloud and sky observations using their GLOBE cloud charts. Energy budget calculations and measuring the optical effects of aerosols in our local area filled a good portion of the lab times. Students compared their data with NASA AERONET aerosol optical depth, GOES-East AOD values, and AppalAIR meteorological and aerosol measurements to validate their work so far. Wednesday's weather balloon launch was a definite high point for many participants and staff. Dr. Bruce Doddridge, the Chemistry and Dynamics Branch Head, joined the workshop from NASA's Langley Research Center to inform students about how this research is applied around the United States and the world. Discussions and comparisons of the movies Inconvenient Truth and Great Global Warming Swindle generated a lively group discussion later in week. A great round of Climate Science Jeopardy rounded out a stimulating three days of investigations with the Appalachian State University staff.

Students received instruction on the properties of light and measurement of diffraction using light benches. They were also involved in two sessions inside the StarLab Portable Planetarium to introduce differences in optical and radio observing in astronomy. Students were trained to remotely observe using PARI's Smiley and the MicroObservatory.org systems.

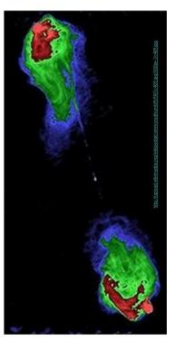
Students returned home Saturday with tools and contacts in climate and space science for their own future research and educational opportunities. They also found new friendships in the homeschool community.

DUKE TIP**, ABOVE AND BEYOND: ASTRONOMY, PHYSICS, AND ASTROBIOLOGY**

2012 Students and Staff



During the field study, students worked in research teams of three. The results of the ten teams' research are presented in poster format and are reproduced on the following pages.



Cygnus A

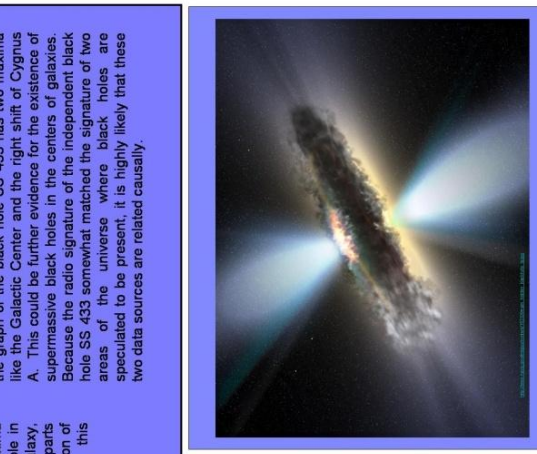
THE TEAM

PARI

BLACK HOLE RADIO

Duke Tip

Alex Moushegian Andrzej Richardson Elijah Hendrickson
Duke Tip Summer 2012 Research Project
6 / 18 / 2012



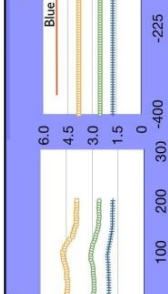
SS 433

THE TEAM

Purpose

This research project was intended to study whether the similarities between the radio signals from individual black holes and from galaxies is further evidence for supermassive black holes at the centers of spiral galaxies. To do this we had to find an sample black hole and a sample galaxy. We chose the black hole SS 433 and the galaxy Cygnus A. We also looked at the Galactic Center for a look at the closest example of a speculated supermassive black hole.

All Cygnus A



The graph of Cygnus A represents the radio signal that is to be expected from a distant galaxy. The signal is shifted to the right, which means that the galaxy is moving away from us. It is a simple graph that is used to show that galaxies emit radio signals as well as visible light.

All Galactic Center

Because the Galactic Center is so close relative to the other objects we have been viewing, it's graph gives a more detailed view of the radio emissions from galaxies. It has two maxima, or bumps, rather than one.

All SS 433

The graph of the black hole SS 433 is a very important thing to dissect. The rising to the left of the maxima can be attributed to the position of the black hole in the night sky. Because it is in the Milky Way Galaxy, the radio noise seen here is the signal from other parts of the Galaxy. We needed to look at an estimation of what the graph would look like without this interference.

All SS 433 Edited

Here, without the radio interference, you can see that the graph of the black hole SS 433 has two maxima like the Galactic Center and the right shift of Cygnus A. This could be further evidence for the existence of supermassive black holes in the centers of galaxies. Because the radio signature of the independent black hole SS 433 somewhat matched the signature of two areas of the universe where black holes are speculated to be present, it is highly likely that these two data sources are related causally.

Research on the "Double Hump"

The double hump that appears in the graphs of the Galactic Center and SS 433 are possibly due to two readings from separate objects. In front of the Galactic Center, there is likely a blob of matter that is giving the last hump, and the two humps on SS 433 are likely due to the two ejections from the poles of the black hole.

We took the measurements and found that:

The blob is about 3627 parsecs in front of the Galactic Center, moving at 8450 m/s.
SS 433 is moving slightly towards us. One jet is emitting at 5172 m/s towards us and the other is emitting at 21126 m/s away from us.
The mass of the Galactic Center is about 6E+35 and the mass of SS 433 is about 1E+35.

Conclusion

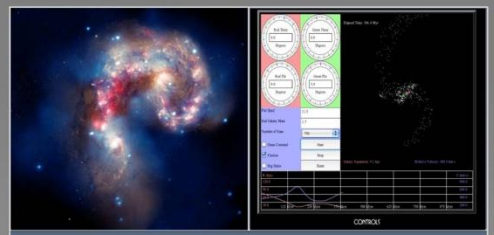
While this is not conclusive evidence for the central supermassive black hole due to accuracy errors in measurement, the similarities between radio emissions from galaxies and black holes are not to be ignored. There is evidence that black holes emit radio waves similar to the ones we see coming from the poles of galaxies. The masses between the Galactic Center and SS 433 are very similar as well. Whether these two factors are causally related is still in question.

Colliding Galaxies

Authors: Erin Puckette[1], Elizabeth Watkins[2], Alexandra Keleti[3]
Duke TIP 2012 Summer Field Studies
Ashley Hall[1] - Westminster[2] - Blue Valley North[3]

Introduction

During its lifetime, a galaxy goes through many collisions. Many of these are strong enough to majorly change each galaxy's structure and evolutionary process. During a collision, the interstellar gases of both galaxies interact with each other. This often results in the formation of new stars. The strength of a collision depends on the mass, distance, and density of the galaxies involved. A strong collision can majorly alter both galaxies involved.



Antennae Galaxies

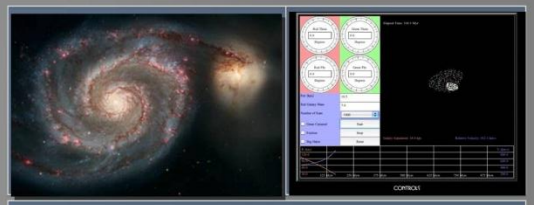
In our simulation of the collision of the Antennae galaxies, the ratio of the two masses was 1.7:1, and friction between the two galactic centers.

Effects of Galaxy Collisions:

Galaxy collisions force the formation of stars and often majorly alter the evolutions of the galaxies. These effects take place over a long period of time. Transient events are relatively faster events that occur shortly after two galaxies collide. These include compression waves in ring galaxies and exchanges of material between the two galaxies involved. Most of the material transferred is interstellar gas. A mass transfer can significantly alter the evolution of both galaxies. Other effects of galactic collisions can consist of induced galactic bar formation and induced star formation.

Galaxy Collisions:
What are they?

It would be more appropriate to dub what we researched "galactic interactions", because when two galactic planes intersect, there isn't much matter colliding. This is due to the vast amount of empty space in galaxies. In fact, the probability that there would be a star-on-star collision is approximately zero percent. Two galaxies are said to be "colliding" when they are at a close enough proximity to cause one to influence the behavior of the other. These interactions take place over millions of years. Usually it's the interstellar gas and dust that interacts with each other. Friction between these gases often causes new star formation. There are also often exchanges in material between the two galaxies. It should be noted that most galaxies involved in collisions were originally part of the same galaxy cluster. Collisions usually involve a large galaxy and dwarf companion. The chances are slim that a collision would occur between two large galaxies coming from separate galaxy groups.



M51a & M51b

Acknowledgments
Crash Course would like to thank the PARI and Duke TIP staff for all their guidance.

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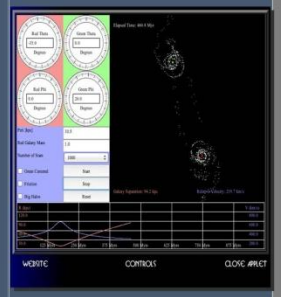
http://burro.cwru.edu/JavaLab/GalCrashWeb/
http://www.nasa.gov/home/index.html
http://nsd.ipac.caltech.edu/level5/Arp/Arp_contents.html
http://www.public.iastate.edu/~curl/sg/homepage.html
http://curious.astro.cornell.edu/question/php?number=331

Software:

The software used to create the simulations is called GalCrash. This software simulates a collision of two galaxies; it takes certain variables into account such as each galaxy's inclination, mass, and the shortest distance between the galactic centers. A graph tracks the relative velocity of each galaxy and the distance between each galactic center.

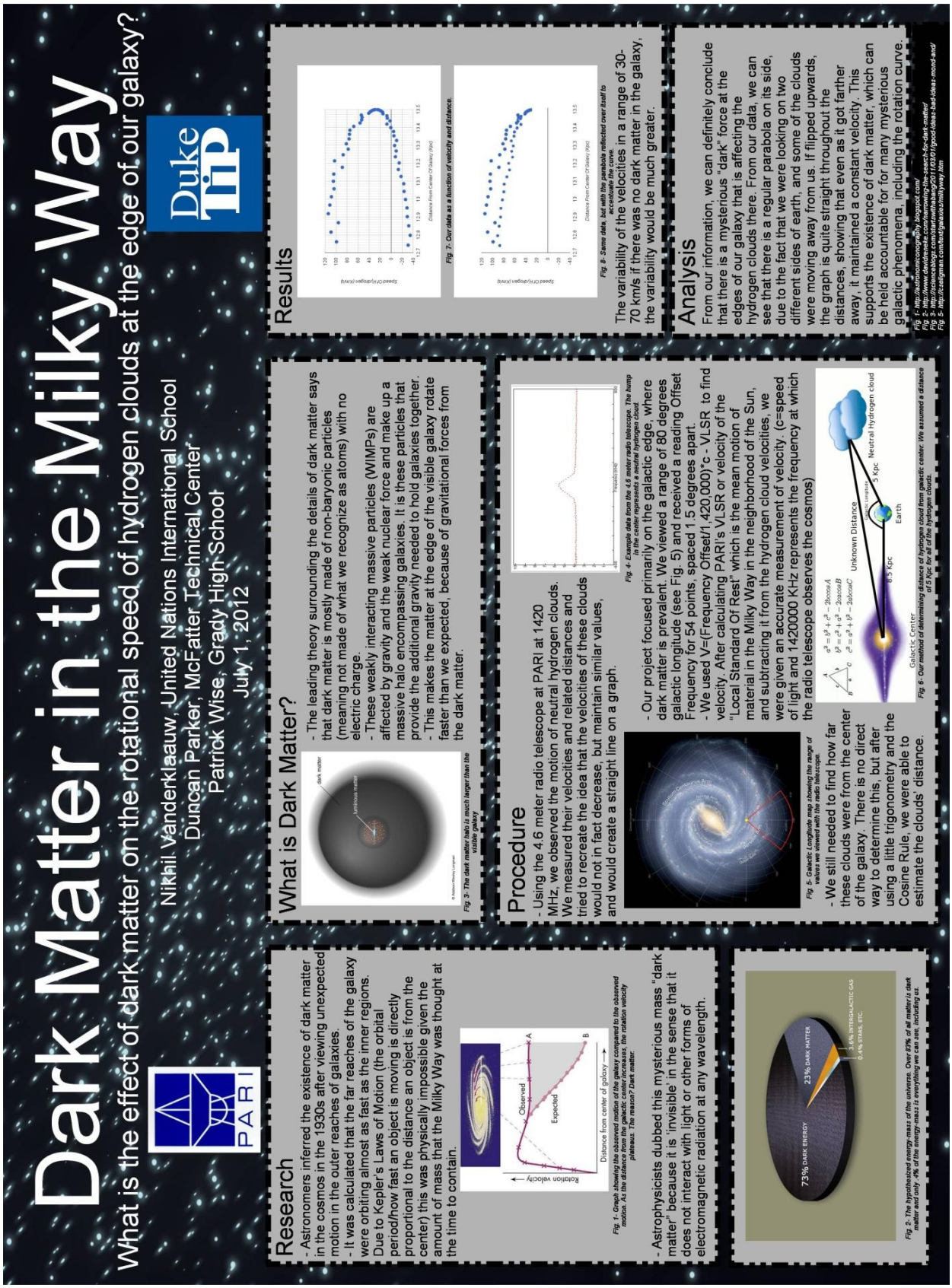


Milky Way & Andromeda

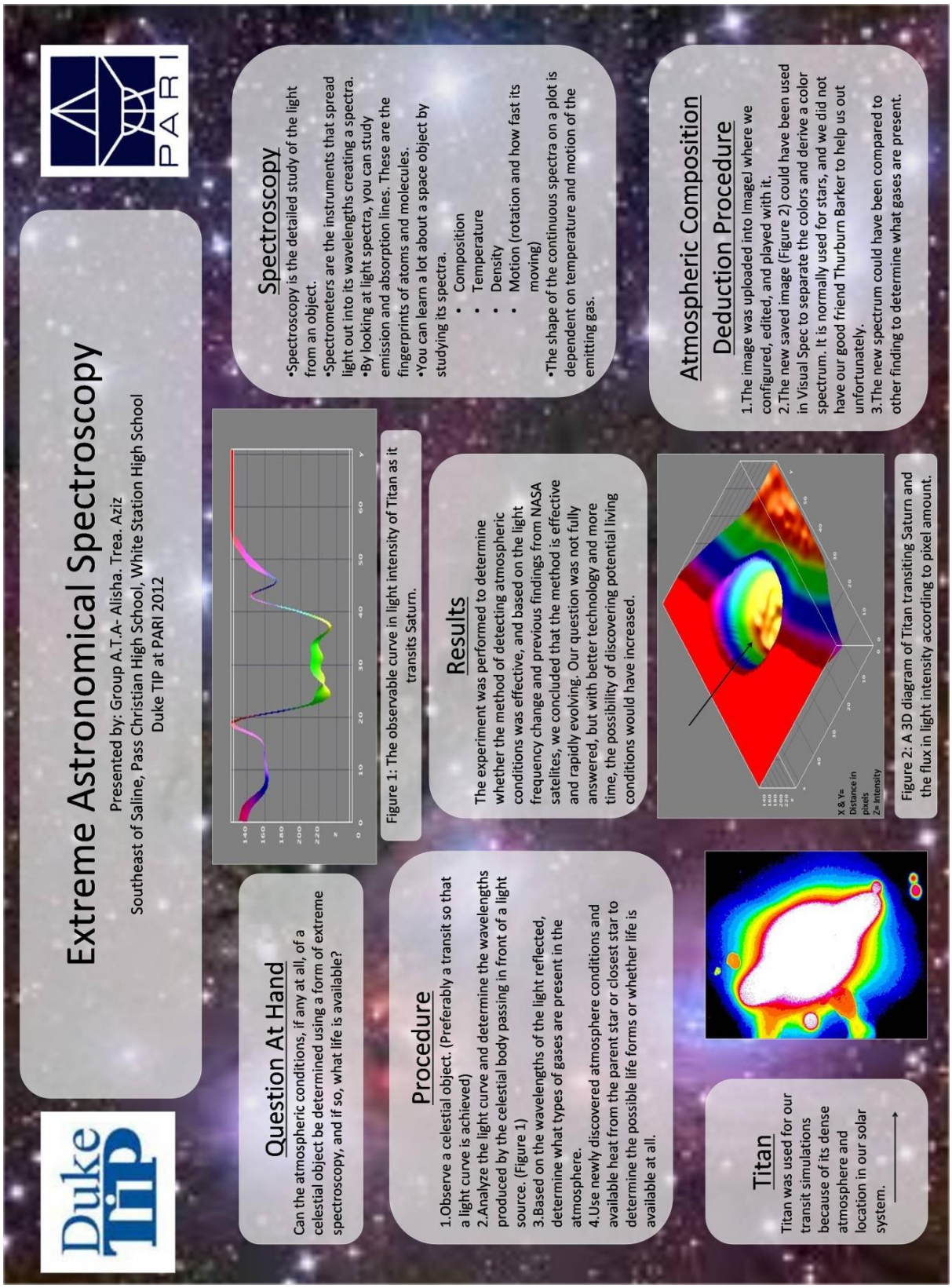
The shortest distance between the two galactic centers in the simulation of this collision is 10.5 kiloparsecs and there is friction between the two galactic centers at some point of the collision.

Classifications of Galactic Collisions:

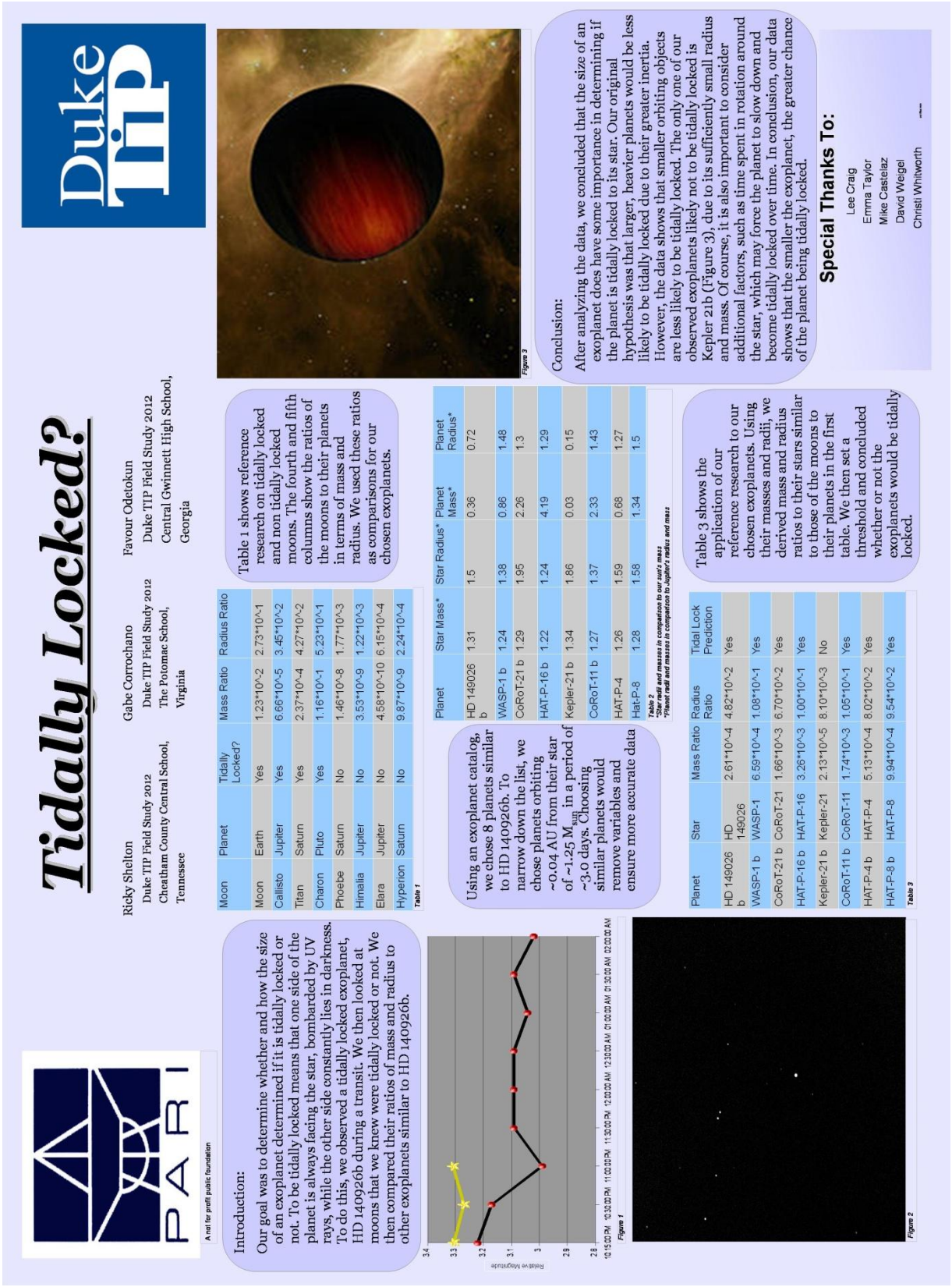
The most violent of galactic interactions are mergers. A collision is considered a merger when the galaxies combine to form one new galaxy. Mergers are classified based on the size of each galaxy, the number of galaxies involved, and the amount of gas each galaxy contains. A merger is labeled major if both galaxies are approximately the same size. It's minor if the galaxies majorly differ in size. A binary merger is a result of two collided galaxies, while a multiple merger is a result of three or more collided galaxies. Mergers are classified as wet, dry, or mixed depending on the gas concentration of each galaxy.



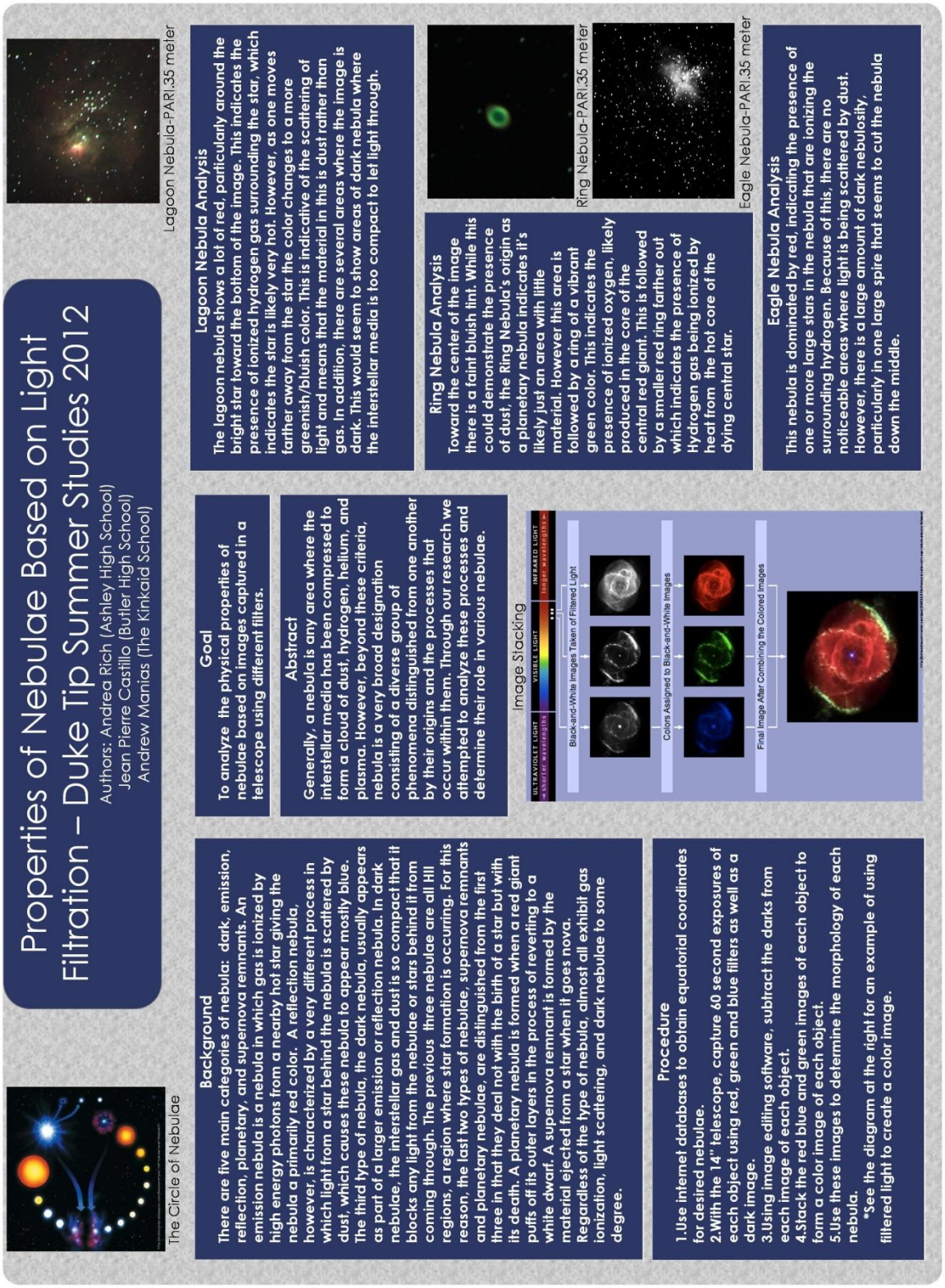
N. VANDERLAAUW, D. PARKER, P. WISE. "DARK MATTER in the MILKY WAY"



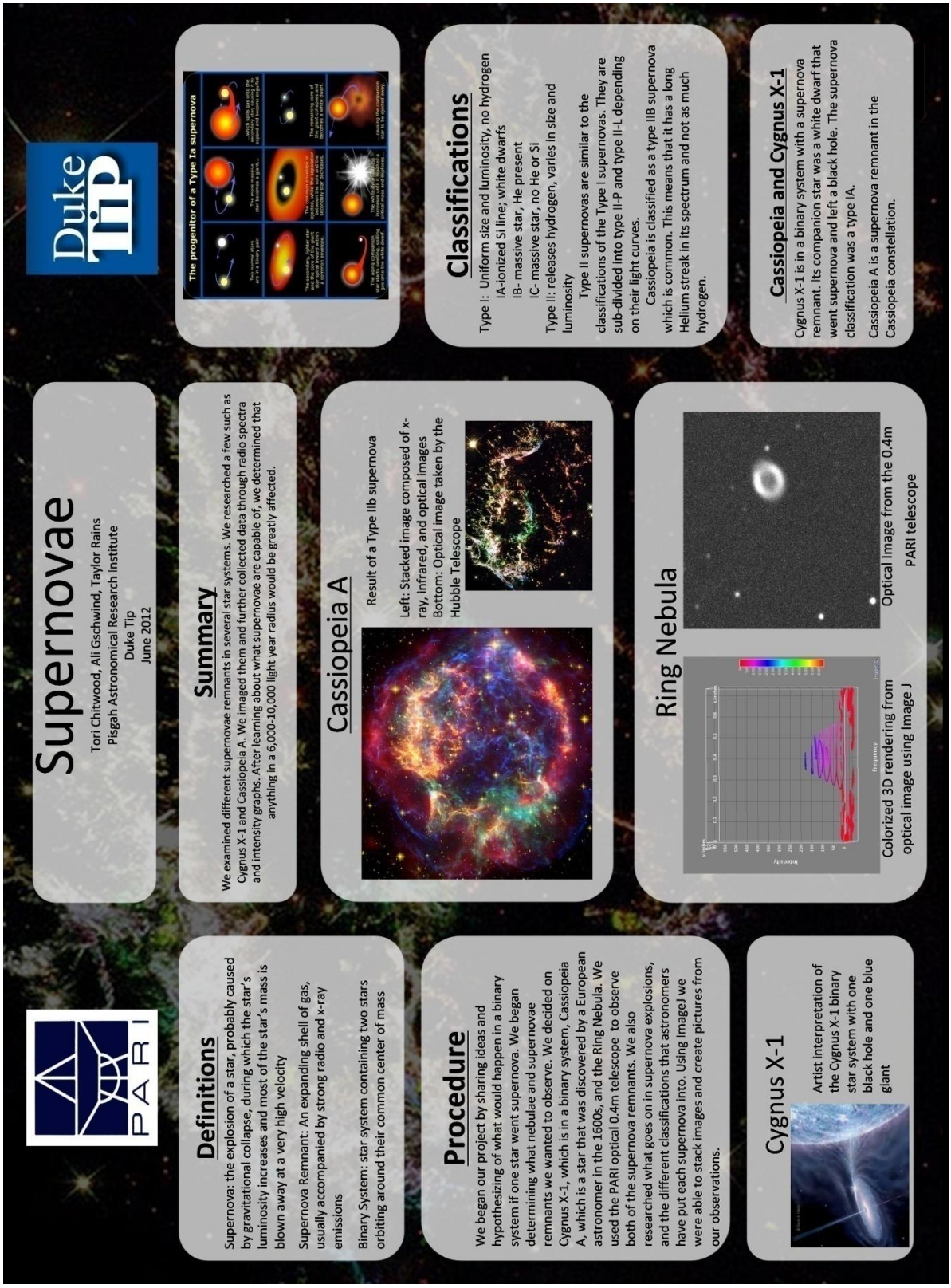
A. PTACEK, T. LADNER, A. MINARECI . "EXTREME ASTRONOMICAL SPECTROSCOPY."



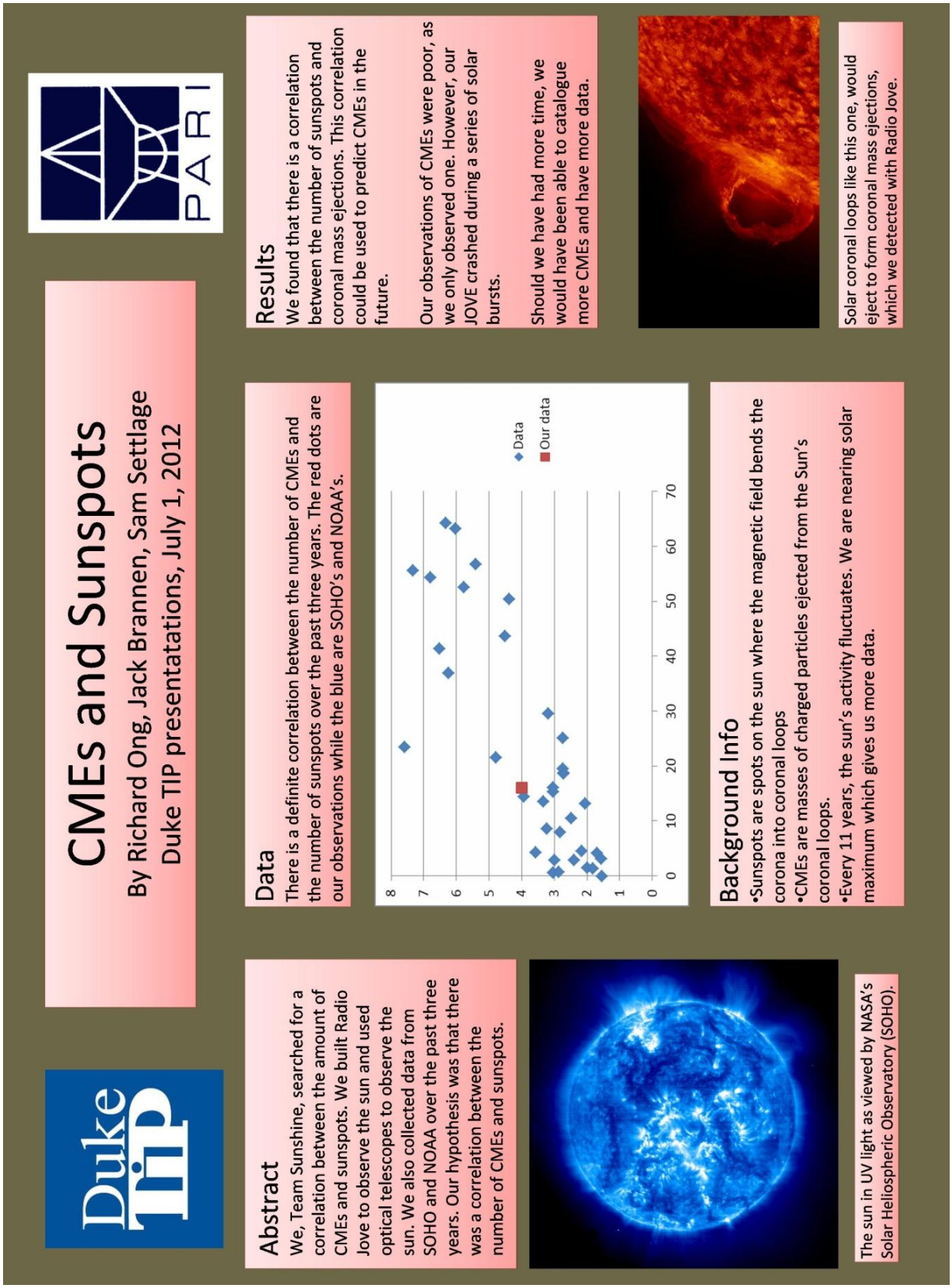
R. SHELTON, G. CORROCHANO, F. ODETOKUN. "TIDALLY LOCKED?"



A. RICH, J.P. CASTILLO, A. MANIAS. "PROPERTIES of NEBULAE BASED on LIGHT FILTRATION."



T. CHITWOOD, A. GSCHWIND, T. RAINS. "SUPERNOVAE."



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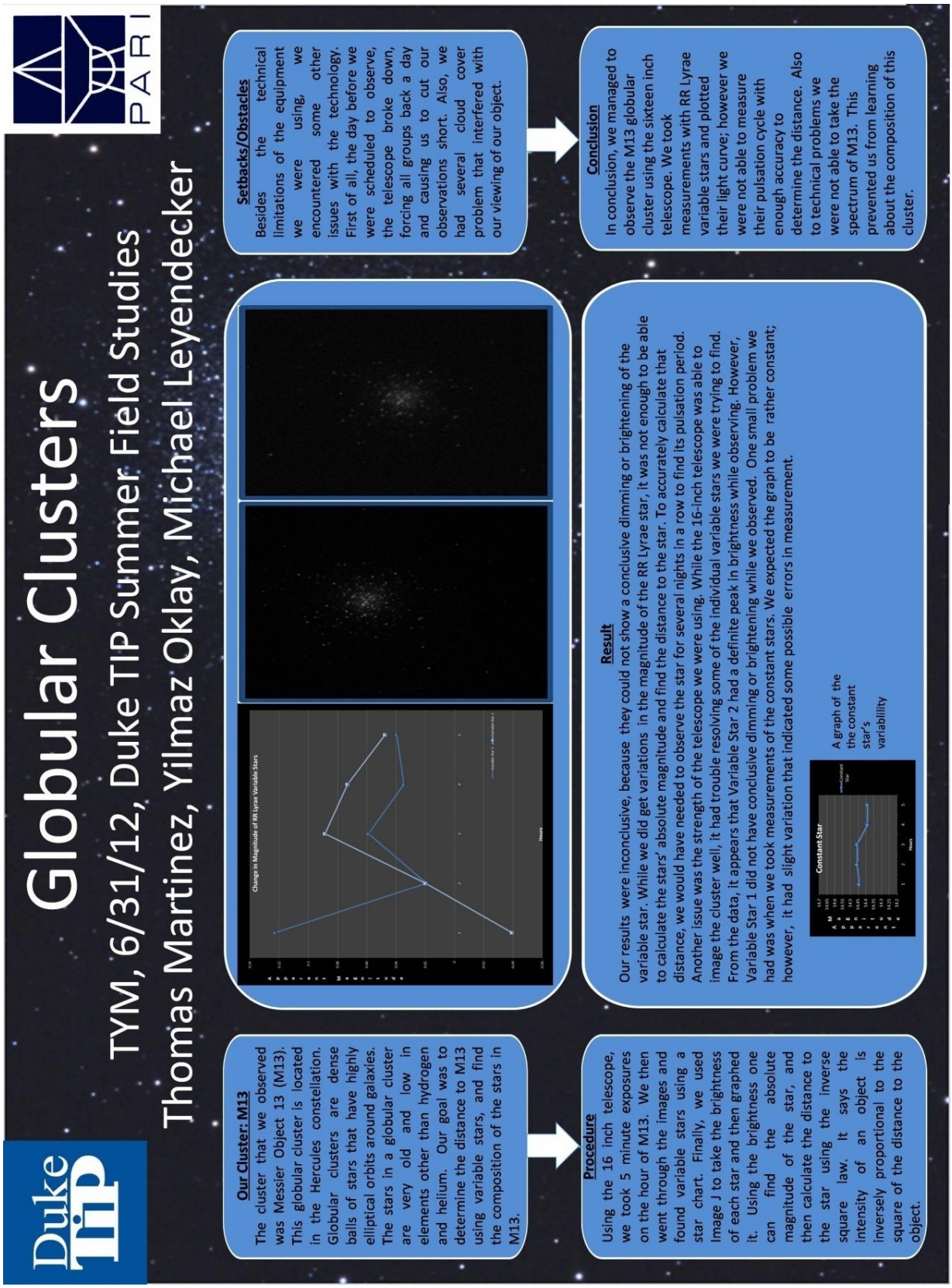


T. MARTINEZ, Y. OKLAY, M. LEYENDECKER. "GLOBULAR CLUSTERS."

Magnetars

Duke TIP Feld Study:
Above and Beyond
June,2012

Erica Nathan[1], Rebecca Pringle[2], Sophie Williams[3]
Florida Virtual School[1], Deerfield Beach High School[2], LAMP High School[3]

What is a Magnetar?

A magnetar is a rare type of neutron star that is surrounded by an extremely strong magnetic field. This magnetic power can reach up to ten gigsteslas. Earth's magnetic field is 0.6 Gauss while a magnetar is 10^{15} Gauss. Over time, the field decays, resulting in erratic emissions of x-rays and gamma rays.

Magnetars are formed from supernovas when gravity acts on the remnants of the explosion, leaving behind an extremely dense core of neutronium (atomic neutrons), a neutron star. A process called dynamo action uses the lines to build up the star's total magnetic field, resulting in the emergence of a magnetar.

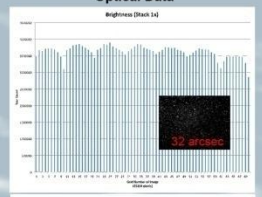
A magnetar's field is the energy source for emissions. In the case of a magnetar, the field causes breaks or shifts in the crust of the star (starquakes), which leads to bursts of high wavelength radiation.

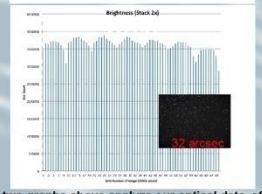
SGR 1806-20

SGR 1806-20 is 50,000 light years away Located in cluster 1806-20, which is in the middle of W31, one of the largest H2 regions in the Milky Way It also has the highest magnetic field of any known object in the universe. The RA and Dec is 18h, 08m, 39.329s and -20degrees, 24', 39.94''. It emits mostly x-rays and gamma rays, giving it the title of SGR (soft gamma repeater). On December 24, 2012, it gave a cosmic blast illuminated the Earth's upper atmosphere. It occurred very brightly in every wavelength of the electromagnetic spectrum. In that tenth of a second, it gave off more energy than our sun outputs in 100,000 years. It momentarily blinded some satellites with its intensity.

Results

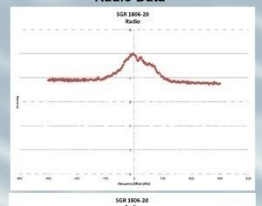
Optical Data





The two graphs above analyze our optical data, after stacking our images The first is stacked once, the second is stacked many times, The results vary slightly for each graph. The images we analyzed are also included.

Radio Data



The first visual is a spectrum scan taken by Smiley. The second is a graph made from the scan. The background radio is subtracted from the graph. There is a sudden peak, possibly from the magnetar.

Procedure

Our goals were to locate and image a magnetar using optical and radio telescopes. We also wanted to observe the properties of SGR 1806-20 from the gathered data.

To achieve this we needed the 3.5m optical telescope, Smiley (4.6m radio telescope, ImageJ, Stellarium, and MicroObservatory. First, we pinpointed our magnetar using Stellarium. Then, we took over twenty sixty-second optical exposures using the luminance filter of SGR 1806-20 on the 3.5m telescope. Our next procedure was to analyze and compile our data. We used ImageJ to subtract noise. MicroObservatory allowed us to stack the images. Again, we used ImageJ to find the brightness of our image to see if there were any irregularities. Star gauging or star counting involves dividing the survey of the sky into grids and counting the number of stars in each grid square If there is a peak or trough in the number of stars per grid square, we know there is an irregularity. We also used Smiley to gather five spectrums of our magnetar. We graphed the data Smiley collected and analyzed the peaks and troughs.

Conclusion

Our optical exposures were largely unsuccessful because of the magnetar's size, distance from Earth and location in a cluster; however, our radio images gave us insight into the relationship between a magnetar and its supernova. The magnetar must have retained remnants from its supernova origin close around it to be detected at this wavelength. Future research on magnetars would need to be done in a larger range of wavelengths and with more images to be able to picture the magnetar more precisely.

E. NATHAN, R. PRINGLE, S. WILLIAMS. "MAGNETARS."

PARI EDUCATOR FELLOW
LEE CRAIG
YORK TECHNICAL COLLEGE FELLOW

Nestled in the Pisgah National Forest near Brevard, North Carolina, the Pisgah Astronomical Research Institute (PARI) is a working astronomical observatory. The facility was built in 1963 by NASA to monitor manned space flight and was later used by DOD/NSA/CIA for satellite signal intelligence. It is now owned and run by a non-profit organization to provide research facilities and science education opportunities.

PARI works in conjunction with Duke University's student talent identification program (TIP) to annually bring 30 high students on campus for an intensive two week research experience. This year I was able to attend the camp as a guest "Science Educator" from June 15 to July 1, 2012. The following lectures were presented to the students to give them a background in Astronomy. I presented the two and a half lectures in bold print.

- Nature of Light
- **The Celestial Sphere**
- **Stellar Astronomy**
- Planetarium Time
- Galactic and Extragalactic Astronomy
- Radio Astronomy and **Radio Telescopes**
- Radio Telescope Operation
- Atmospheric Dynamics
- Astrobiology
- Cosmic Ray Physics
- Extreme Scattering Events
- Meteorites
- Optical Telescopes
- Optical Telescope Operation
- Pulsars and Radio Interferometry

The students were mentored in performing and presenting original astronomical research. This year the student projects were as follows:

- Are radio signals from individual black holes and from galaxies further evidence for supermassive black holes at the centers of spiral galaxies.
- Is there a correlation between the number of Solar sunspots and frequency of coronal mass ejections.
- Local effects of supernova remnants
- Properties of Nebulae
- Energy emission from magnetars
- Does an exoplanet's mass affect its likelihood to be tidally locked
- Can extreme astronomic spectroscopy help determine atmospheric conditions on exoplanets or distant moons
- Using brightness variation in RR Lyrae stars to determine magnitude and galactic distances
- Determining composition of stars in globular clusters
- Measuring the effect of dark matter on galactic rotation in the Milky Way galaxy

- Are radio signals from individual black holes further evidence for super-massive black holes at the centers of spiral galaxies
- Types and effects of galactic collisions

Each research group prepared and presented a slide presentation and a poster. The research was performed using the following PARI resources:

- 0.4 m (16”) Meade optical telescope with a CCD camera
- 0.35 m (14”) Celestron optical telescope with a CCD camera
- 4.6 m radio telescope
- A radio Jove dipole radio telescope
- The Astronomical Photographic Data Archive, housed at PARI

My duties included the following:

- presenting the two and a half lectures
- teaching and helping students to use the 0.4 m optical telescope and the associated software to control the telescope, camera and edit the resulting images
- continue the students observations until 2 am exposing images after they went to bed
- answering questions relating to their projects and Astronomy
- helping their research to progress
- other general cleanup, building and fixing stuff
- working with the students in a camp environment

My objectives for initiating and completing this professional development experience were fully met, as I was able to accomplish the following:

- observe the process of guiding students to complete original scientific research
- being immersed in the atmosphere and culture of a working observatory
- listening to a series of excellent lectures on a wide range of topics dealing with Physics and Astronomy
- gain firsthand experience with the procedures and tools of observational astronomy
- reacquaint myself with science and research, as opposed to strictly science education

This was a invaluable learning experience, and I would like to thank Dr. Michael Castelaz and Christi Whitworth and the entire staff at PARI for allowing me to come, serve, work and study at PARI. I have gained a wealth of information and experience that I plan on incorporating into my classes very quickly.

CALIBRATION SOURCE FOR THE PARI 4.6-M RADIO TELESCOPE

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The 4.6-m "Smiley" Radio Telescope

I worked on installing and defining a new calibration device for the PARI 4.6m Radio Telescope. The 4.6m dish is also referred to as "Smiley," due to its paint resembling a smiling face. Smiley detects at the 21cm wavelength, so data collection and calibration will be performed at this wavelength. In every data set, the data is collected in bins 5KHz apart. For the purpose of the project, the gain for the 4.6m telescope was set to 16 to ensure that the changes in intensity were more observable without the intensities experiencing overflow. The purpose of this project was to install the noise source and develop a method to use the calibration device effectively in order to enhance and expand the data acquisition features of the 4.6m Radio Telescope.

We obtained an electronic noise source, as seen in Figure 1, the same as described in Montez's article, and is in use as a electronic noise calibrator "for MIT Haystack Observatory's Small Radio Telescope" for REU purposes (Montez, 2011). What the electronic noise source does is produce a signal at the 21cm wavelength that the MIT SRT detects as 200 Kelvin. Although the 4.6m telescope's receiver is further away from the noise source compared MIT's SRT, we are assuming that the value is still 200 Kelvin until the system is capable of discerning otherwise.

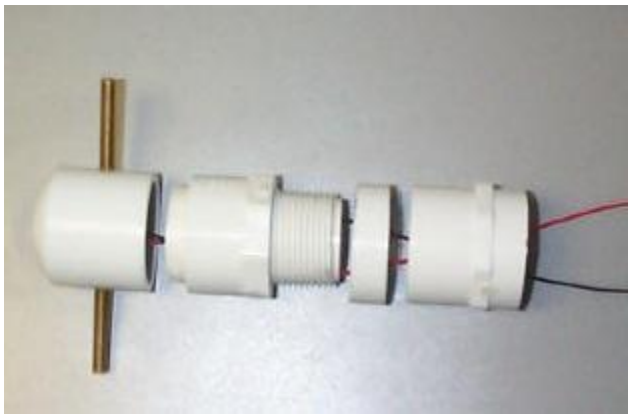

Figure 1. An image of the noise source, from Montez's article. It shows the dipoles that need to be aligned with the receiver. All pieces screw together.

The noise source was installed at the center of the dish, and to do so for Smiley, we enlarged the drainage hole in the center by a quarter of an inch in diameter, and fed the wires for the device through, finally setting the device safely snug, facing the receiver. The dipoles on the noise source need to be polarized with the receiver, or else the amount of noise detected is

diminished or not noticed at all. Any deviations from the maximum temperature the noise source is supposed to produce can impact data analysis negatively.

Because the noise temperature reading can differ in different parts of the sky, we used the south hill, a constant noise source, to calibrate Smiley. PARI is located in the mountains, and pointing at the hill is within the physical capabilities of the telescope, pointed at 180 degrees in azimuth and 10 degrees in altitude. The ground emits a noise reading of approximately 300K at our wavelength. The 4.6m telescope cannot automatically detect what temperature the sources it points at are, so the equation

$$(1) \qquad Y = \{T_g+T_r\}/\{T_o+T_r\}$$

is needed to determine what the temperature (K) and brightness (Jy) are of the objects we observe. In Equation 1, Y is the ratio between the noise source being on and off, T_r is the temperature of the receiver, T_o is the temperature of the background where we are pointing the 4.6m telescope when calibrating (300K), and T_g is the temperature the noise source produces (200K) plus T_o. The relationship between the temperature of an object (K) and the brightness (Jy) can be represented as 1 K =166 Jy, which is then used to convert temperature to brightness and vice versa.

Because the temperature of the receiver is subject to change due to the conditions of the surrounding environment, the value for T_r must be calculated before every observation in order to ensure better precision in data collection. To find the temperature of the receiver, we use

$$(2) \qquad T_r = \{(I_1*T_g)-(I_2*T_o)\}/\{I_2-I_1\}$$

Where I_1 is power level of the sky and receiver, and I_2 is the power level of the sky, receiver, and the noise source. The other variables are the same as in Equation 1. These two equations are then utilized to determine the temperature of the observed source.

I initially used Scilab, a free program similar to Matlab, to use the equations and develop a program where the user can input the frequency of the data point, I_1, I_2, and the relative power of the source itself, and obtain as output the temperature of the object at whatever frequency it is situated at. Primarily, Scilab was utilized in checking that the data had been collected properly, and that values were either close to accepted values or consistently a certain amount higher or lower than expected.

To fit the needs of a person of any academic level, the final version available for the public's use is an Open Office Spreadsheet. The spreadsheet uses three 'sheets' in the file, and the only information that needs to be inserted is on the first sheet. The inputs are, in order: Frequency (Khz), Intensity Of Target, Intensity Noise Source Off, and Intensity Noise Source On.

There were discrepancies on what method should be used to calculate from the values we obtain from Equations 1 and 2 the actual temperature of the targeted source, so two spreadsheet files were created – one utilizing ratios and the other assuming that intensity of zero corresponds to a value of 0K. Neither spreadsheet is completely accurate, but as of right now the latter procedure is more accurate. I will describe how the two files differ from each other as I explain how the spreadsheet works.

On the first 'sheet' of the file, after the four inputs, there is Temperature of the Receiver and either Ratio between Source On and Source Off Intensity or Temperature per Intensity Division, depending on whether the ratio or non-ratio file is used. The second sheet displays all columns from the first sheet save for the frequency values, and includes more columns to the right which then calculate the Temperature (K) and Brightness (Jy) of the radio source being

observed. The third sheet displays three graphs, the top left graph being an intensity graph of noise source on, noise source off, and pointing at the radio source per binned frequency (KHz). The other two graphs display the temperature (K) of the object per binned frequency (KHz) and brightness (Jy) of the object per binned frequency (KHz).

As of right now, the two spreadsheet files are inaccurate, for they do not account for atmospheric conditions, which can account for up to a 200K difference in observed values. For future projects, it would be beneficial for a person to develop a way to account for these changes for the analysis of Smiley data. The ratio spreadsheet has to have minor tweaks applied to it in order to be as accurate as the spreadsheet assuming an intensity reading of zero is equivalent to 0K. The inherent problem with assuming that zero is equal to 0K is that 0K is not at where the intensity reads as zero, but because this problem is approximately equivalent for every observation, all results should yield brightnesses that will consistently be higher than the expected values.

Another slight impediment as of right now is that occasionally the 4.6m telescope won't register a data point, so two sweeps are used per observation in order to ensure that there is a data point for every frequency used. It is unknown whether this problem will go away once the 4.6m telescope is fully upgraded or if running two sweeps will need to be standard for this system.

One of the other interns, Matt Grimes, developed a button for Smiley's on-line application which will move the 4.6m telescope to the appropriate position and take data with the noise source both off and on. This will be beneficial to anyone operating Smiley in the future. Also, after multiple uses, it did not appear that the noise source had deviated from being aligned with the receiver at all, suggesting that it is safely snug attached to the 4.6m telescope and can be used for future research or teaching modules.

Mentoring Students in the Duke TIP Program

I helped with the Duke TIP program that was held at PARI. I assisted many groups in the acquisition and analysis of data from the 0.4-m optical telescope with an Apogee Alta E42 CCD Camera and the 4.6m Radio Telescope, along with assisting the counselors in documenting and photographing TIP student presentations. Figure 2 shows me working with one of the TIP students. Further details are provided below.

Figure 2. Demonstrating to a TIP student how to dark subtract and build an RGB image

Duke TIP is the Talent Identification Program that selects gifted and talented high school students and sends them to various locations across the country to dive headfirst into a subject of their interest. Pisgah Astronomical Research Institute houses the Astronomy, Physics, and Astrobiology program, where 30 students live on campus for two weeks to learn about and research topics that intrigue them the most.

I helped teach the students how to setup for observations using TheSky program (a program that has well-known objects in its database and points the telescope to the RA/DEC of the object one needs to observe) or the RA/DEC function in the telescope control program. Through this program, the student can click on the object in the sky at the moment, or search for an object that might be harder to find, then synchronize the telescope and have it slew to the object selected.

The students also used MaximDL, which controlled the CCD camera and the exposure settings. The students took pictures ranging form 60 seconds to 300 seconds, using either clear, red, green, or blue filters. I helped the students learn how to utilize ImageJ for image processing, and MaximDL or MicroObservatory when the students needed to produce RGB pictures of their objects. ImageJ is a program that is commonly used for photometry, and has many math functions that can be used to clean up images or make them look more asthetically appealing. I helped a few groups learn the ropes of understanding Smiley's (the 4.6m Radio Telescope) interface and how to read the data Smiley produces.

To produce the RGB images, the students first took images with a red filter, a green filter, and a blue filter, all of the same exposure time. Then, we instructed the students to dark subtract, which is to subtract the values of the pixels when the camera shutter is closed. By doing this, the students helped to eliminate much of the hot pixels, making their images cleaner. The students then used a RGB color stack in MaximDL, where it would align using two objects in all three pictures and produce a color image. If the students computer could run MicroObservatory correctly, they used that program's version of the RGB color stack to produce the same effect.

There were times which prevented the TIP students from finishing all of their observations before their required bedtime. In these situations, both myself and Lee Craig, a staff member who worked with the TIP students, would observe the objects the students still needed. I also took pictures to document the students presentations and events for the program.

The VELA Antenna Project

I worked, with the help of Dr. Moffett (Furman University) and Dr. Castelaz, on a structure that could potentially detect radio signals from the Vela pulsar in the 300MHz range. It is a pulsar situated in the constellation Vela, with a period of 89.328ms and right ascension of 8:35:20.61149 and declination of -45:10:34.8751. At the Pisgah Astronomical Research Institute, due to the latitude and elevation, the vela pulsar does not rise above 10 degrees over the horizon.

The detection structure consisted of four HGTV antennae, whose signal has been filtered to omit any man-made radio sources, pointed just high enough so that there would not be noise from the ground interfering with any potential data. It was discovered that the antennae had a receiving radius of 10 degrees, which led to concerns over how the amount of noise in the sky affected data collection, especially since the antennae were pointed at slightly different angles from each other and noise is additive. We tested out the apparatus by pointing it directly at the Sun at noon (since it is the brightest radio source in the sky, also it covers half a degree in diameter, much more than any other point source), and still were unable to discern any signal.

From this, it could be seen that the apparatus is incapable of observing the vela pulsar as it is.

Because the initial setup was not capable of taking any data, it was decided to then attempt to detect Vela using Smiley, the 4.6m Radio Telescope at PARI. However, before any signal as small as Vela can be detected, the telescope needs to be calibrated, which is where one of my other projects came into view.

Observations of a Near Earth Object

Near Earth Objects are objects whose orbits at perihelion bring them at least within 1.3AU from Earth. I looked up a list of Near Earth Objects that had an observable Right Angle and Declination to work with, and came up with six objects that were up during the night and had an apparent Visual magnitude brighter than 20.

The telescope that I used was the PARI West Optical Telescope, a 0.4m Optical telescope, f/8, which gives a scale of 64.5 arcseconds per mm. It has an Apogee U42 2048 x 2048 CCD Camera attached, and did not move relative to the telescope for the entirety of the research. Rounded to the nearest hundredth of a degree, the CCD field of view is 0.50 degrees in any given image from the telescope.

Due to hazy or otherwise inclement weather for the majority of the time, it was determined that the best option would be to focus on observing one particular NEO. The Near Earth Object 2002 AM31 was the only object with an apparent Visual magnitude brighter than 16, so it was deemed the best suited for this endeavor. On July 22, 2012 the NEO 2002 AM31 was at perihelion, 0.035AU from Earth, and had an apparent visual magnitude of 13.7. To ensure that the object was observed, a 300 second exposure was used with the clear filter. The NASA JPL website's section HORIZONS - Web Interface that tracks and predicts the motion of the various NEOs, and a visual representation of the object is seen in Figure 3, from the website. I used their ephemeris that gave predicted positions for this near earth asteroid.

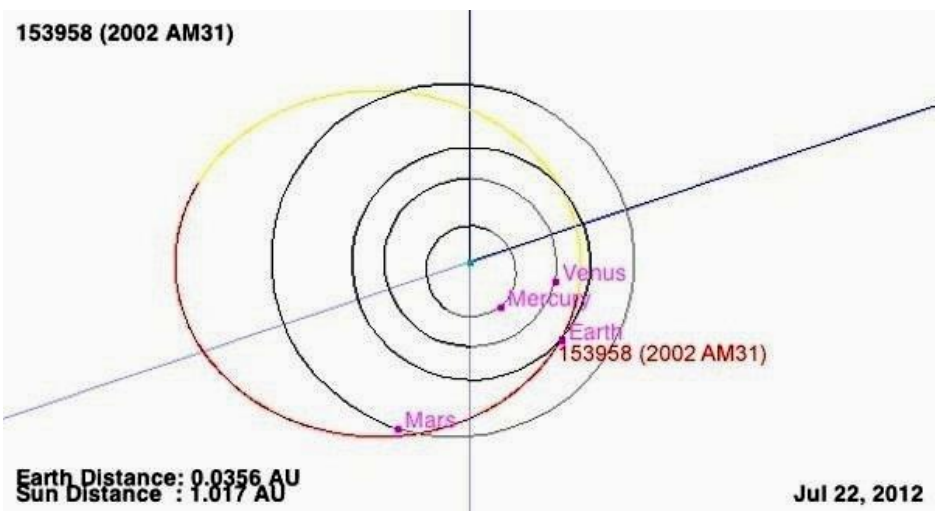

Figure 3. The orbit of Near Earth Object 2002 AM31.

Observations were taken using the DFM - Telescope Control System program. The program allows the user to control everything necessary the telescope had to do during an observation session. Under the telescope - misc. tab, the observer can change the focus of the telescope, along with the commands to open or close the tube doors, which need to be open for

observations. In order for the telescope to track the object, the track rate for RA needs to be changed from 0 to 15 arcsec/sec , done through the telescope - rates tab.

Before any observing was performed, I initialized with fiducials, under the telescope - initialization tab. By doing this the telescope is set up to move to objects at the best of its ability. To direct the telescope to a specific Right Angle/Declination, the coordinates need to be plugged into the telescope - initialization tab as well. From this window, all observations were performed. The main window of the program allows the user to forcefully stop the telescope from slewing if the angle away from the zenith grew too large. For the West Optical Telescope, that angle was approximately 65 degrees away from the zenith.

Once the observations were taken, they were cleaned using ImageJ, an image processing program. I cleaned up the images from the observations by dark subtracting them. Dark subtracting requires two images, the image being cleaned up and an image of the same exposure time taken with the shutter closed. The pixel values from the dark image is subtracted from the former, and results in a cleaner image. After that, I used the brightness contrast window to maximize the visibility of the NEO. The images were color inverted to make them more printer-friendly, and saved as .jpeg files.

Once the images were saved, I then used a program called Aladin, version five, to flip the symmetry of the image because the camera takes pictures that are left/right switched from how they are and to create a grid outlining the RA and Declination, as seen in Figure 4.

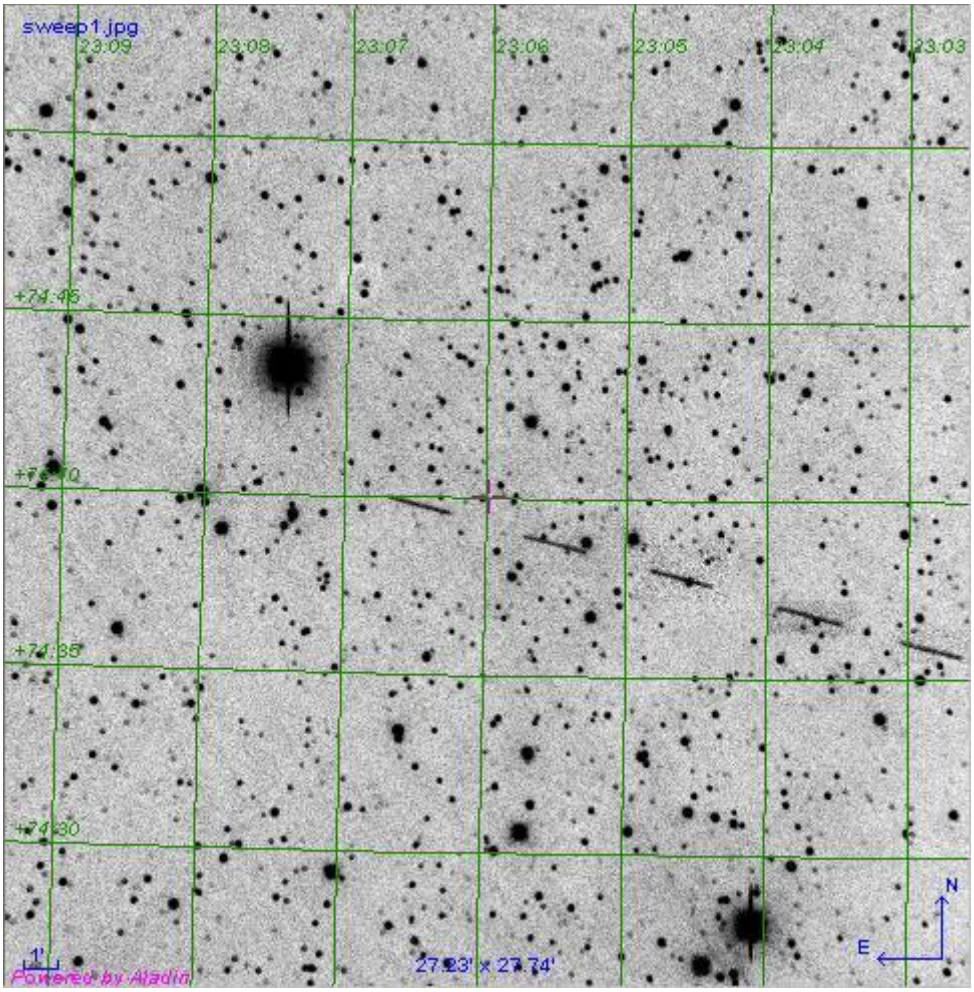

Figure 4. Co-added images of NEO 2002 AM31 clearly show the track of the asteroid as 5 streaks on the image.

I then calibrated the image using the astrometrical calibration function. Using the sky database of SkyView, I plugged in my coordinates and how many degrees the image covered. The website provides an image, including the respective RA and Declination of all pixels represented within the image. I used this image to compare with the one the CCD camera produced, and chose six matching stars with their information to calibrate the image. After an image is calibrated, a grid can be displayed over the picture by selecting the grid tool.

I used Blink Comparator program to upload the images in chronological order of the night, and then calibrate them all so the only object in the image that changed pixel position was the NEO. From this, we can use ImageJ and created an image where the NEO was seen as a moving object through the sky, as a time progression, as seen in Figure 5. This was done using the images taken between 06:51:00 - 07:31:28 UT, July 23, 2012. I compared the calibrated image to the given data from the web interface, and Table 1 shows the first and last observations of the set.

It can be seen by these two examples that the observed RA is between 20-24 minutes greater than the expected values, and the Declination values were all approximately two minutes greater than the expected values. Considering the near consistency of the deviations, it can be deduced that either the expected RA and Declination values were off by the previously stated amounts, or that the calibration process was only accurate to that extent. Possible suggestions for future study could be to try a different calibration method, compare the RA and Declination to the given values and the previously calibrated measurements to help discern where the root of the deviations lie.

Table 1. Observation Comparison

Time (UT)	Status	RA/DEC
06:51:00	Observed	23:02:37.61 +74:35:37.8
06:51:00	Given	23:02:13.95 +74:33:38.0
06:56:00	Observed	23:03:01.84 +74:36:02.7
06:56:00	Given	23:02:41.13 +74:34:06.5
07:31:28	Observed	23:06:15.11 +74:39:32.8
07:31:00	Given	23:05:52.11 +74:37:20.2
07:36:28	Observed	23:06:41.25 +74:39:59.5
07:36:00	Given	23:06:19.49 +74:37:47.0

Acknowledgements
I would like to thank Dr. Michael Castelaz, Dr. David Moffett, Don and Jo Cline, Christi Whitworth, Lamar Owen, and the rest of the PARI staff and volunteers for their support for my various projects.

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Don Cline, Me, and Dr. Castelaz. I wish to thank Don Cline for the opportunity to intern at PARI as the J. Donald Cline Scholar. This has been a great experience!

THE PARI GEOMAGNETOMETER CONTROL SOFTWARE

MENELIK ZAFIR
GEORGIA STATE UNIVERSITY
EDWARD DOUGLAS "CHIP" PARKS INTERN

The focus as a Parks intern at the Pisgah Astronomical Research Institute (PARI) was to switch a Visual Basic 6.0 (VB6) geomagnetometer program into a Python graphical user interface (GUI). In addition to switching the code over to python additional new features were added to the geomagnetometer reader program. The features added were a live online graph of the magnitude, declination, and inclination for over the past six hours. I also added exception handing which the VB6 program lacked. Exception handing is key to insure the program does not crash from non fatal errors such as input data like the VB6 program did. Finally, I made the python version of the geomagnetometer reader a standalone application, which means a user does not need a development environment installed on the client system unlike the VB6 program which required VB6 to be installed on the client system.

The next step was to translate the VB6 into python by first studying the VB6 code and learning how the program communicates with the geomagnetometer and understanding what the program did with the data. I also had to figure out how the VB6 program displayed the data on the geomagnetometer web page on PARI's website. The VB6 program handled the output data by saving it into a ".dat" file locally and onto PARI file server Pachyderm. The VB6 program also generated an html file that displayed the output data in text format on the geomagnetometer webpage on PARI's website.

While interpreting the functions of the VB6 program several issues had to be addressed. One major issue was if Pachyderm was not found the program would not collect data at all. The problem was solved by defining a function that determines if the directory to Pachyderm is available. If Pachyderm is available the programs saves a copy of the output data in Pachyderm and locally, if not it will simply just save the data locally.

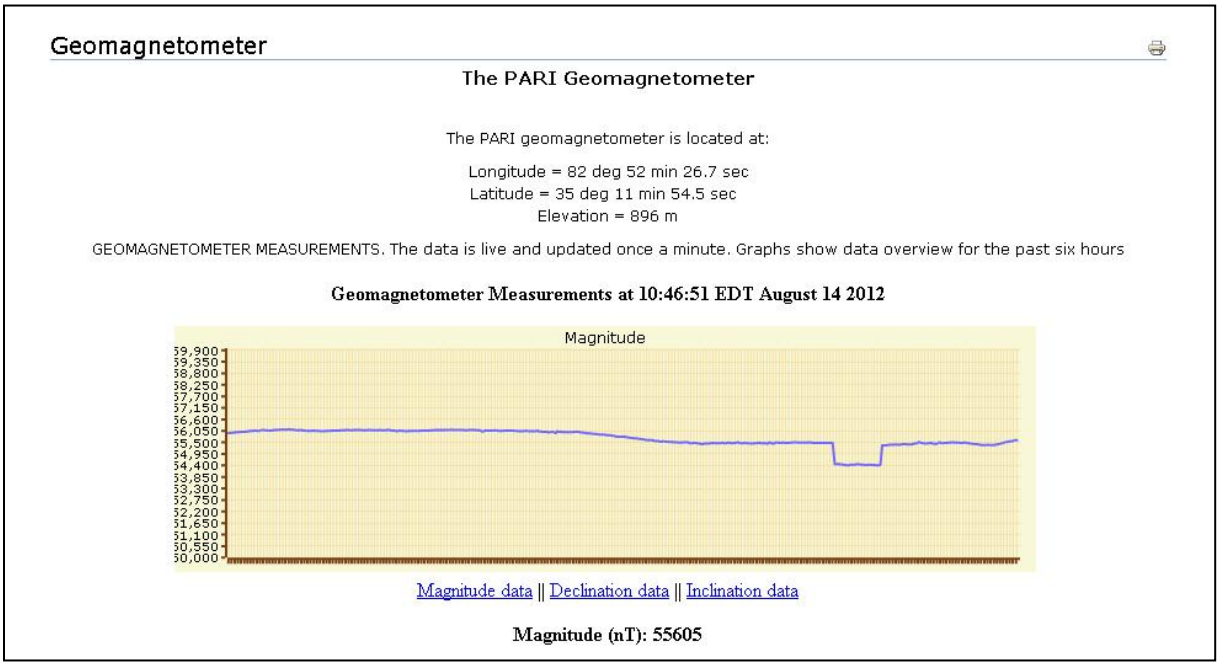
Another issue with the VB6 program was if the directory of the web server is not available the program does not collect any data. I fixed this problem by defining a function similar in the Pachyderm problem, but instead of keeping the text output generated html file a Flash graph was added. The data from the python geomagnetometer program was written to the Flash ".swf" and the file was generated using JavaScript. The online graph was a module called Open Flash Chart 2. It required that I placed a file named "open-flash-chart.swf" in the root of the webpage along with a folder named "js" which contains the necessary JavaScript files needed for the graph to be generated.

Sometimes the geomagnetometer will send out bits of string that are less than the required 19 characters, the VB6 program just reported the calculated erroneous data. I corrected this problem by creating a function that checks the string length and if the string length is 19 characters it calculates the data. If not it will flush the data and wait for another set of string data. One other problem found while making this program was people deleting files needed by the geomagnetometer to run. For example, someone might delete the calibration data file which the geomagnetometer need to calculate data. The VB6 program would crash and not report anything. This was changed by having the python program regenerate the calibration file and directory if deleted and continue with the calculations and output to Pachyderm, Webpage and local directory. Also if the local output directory is misplaced or deleted the python program will create the directory thereby avoiding an error and allowing the program to continue to run and

complete calculations. The VB6 had a status window in the program but it was not complete, it only reported two things which were either “All Systems Go!” or “Systems Not Ready”.

I elaborated on this status function by adding multiple statuses’ which are; “All Systems Go!”, “No Serial Port Connection, Please Check Connections and Start Again” , “Serial Port Connection Timeout, Please Check Connections and Start Again”, “No Geomagnetometer Data Retrying...”, “Pachyderm and Web Sever not found!, Please Check Mapped Drives”, “Pachyderm not found!, Please Check the Pachyderm Mapped Drive” and “Web Sever not found!, Please Check the Web Server Mapped Drive”. These numerous statues were created to aid in troubleshooting in case the program is not working correctly. The status is displayed in the status bar in the bottom of the GUI window. The final change I made to the geomagnetometer was making the program a standalone application; this was accomplished by using the pyinstaller module. This module allows the python application to run on a system without a python installation. If a Windows standalone application needs to be compiled a user would simply go into the Windows command prompt and change directory to the pyinstaller folder. Then run the command “python pyinstaller.py GMag.py” after a copy of the “GMag.py” is placed in the same directory of the “pyinstaller.py” file. I believe I was successful in changing the VB6 program into a better python program, the python program will get better as it goes through the software life cycle and new features and improvements are made.

The geomagnetometer data is now saved and also written to a webpage on the PARI website in real time. The link is http://www.pari.edu/telescopes/geoscience/geomagnetometer/ and an example of the output and graph is shown below.



SUMMER 2012 INTERNSHIP REPORT
MATTHEW GRIMES
EMC INTERN

Project Descriptions

During my internship at PARI in Summer 2012, I worked on two main projects. My first project consolidated the hardware hosting the web application and peripherals used to control Smiley, a 4.6-meter radio telescope on the campus of PARI. The second enhanced the control panel in the web application by adding a feature that allows users to toggle power to the noise source used in calibrating the data from the spectrometer on Smiley.

Initially there were two machines used for the Smiley web application. One machine contained a synchro/resolver card from Data Device Corporation (DDC) that took signals from the encoders reading the horizontal and vertical angles of Smiley and converted them to digital angles. This machine ran a program called SynchroServer which was designed by Joe Daugherty, Professor Emeritus of Computer Science at UNCA. SynchroServer packaged this information and opened a socket connection, sending both angles' data through the socket whenever a request was received. The second machine hosted the web application that included, among other things, interfaces for controlling the telescope, reading from the spectrometer, and viewing and analyzing the data gathered. In a nutshell, all functionality but the ability to read the angles from the encoder was already present on the machine hosting the web application. To retrieve the angles so the web application could use them, this machine accessed the open socket

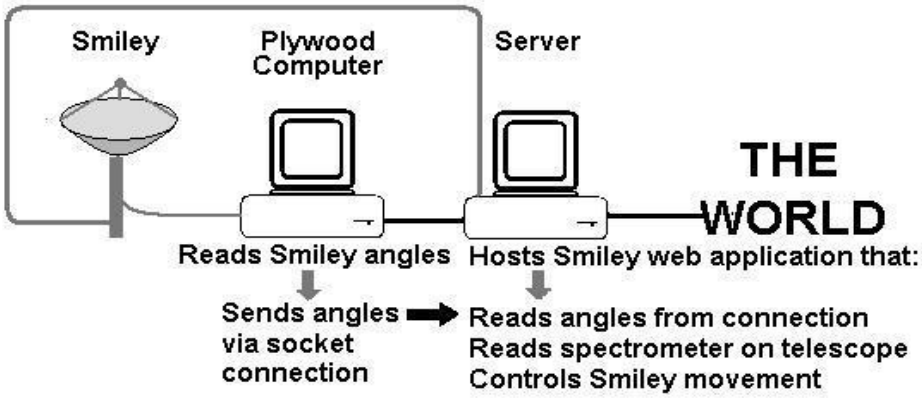


Figure 1 – Previous Smiley Setup

on the computer reading the angles and requested the data.

Project Solutions

Since the new machine would have its own synchro card, I decided the most effective way to keep all functionality would be to modify the version of SynchroServer on the old machine reading the angles to work with the new card and use this version on the new computer. The angle information would still be accessed by the web application via a socket connection, but instead of accessing another computer on the network, the application would be accessing an open socket on the same machine that hosts it.

The main reason I chose this solution is because it keeps modification of pre-existing code to a minimum. Or, to use a platitude, “if it's not broken, don't fix it.” The Smiley web application

was designed and developed years ago by Joe Daugherty and has worked reliably since then. While the web application has been augmented with new features in the intervening years, the improvements are mainly comprised of additions to the existing structure. Modifying SynchroServer to work with the new machine achieves the goal of maintaining all functionality on the same computer without unnecessary modification of the web application's architecture.

To implement this solution, I used Visual Studio to modify the SynchroServer program already implemented in Visual Basic 6.0 to work with the updated card, and then moved the program over to the new computer. I also changed the configuration of the web application to access the socket opened by SynchroServer on its own IP address rather than the address of another computer on the same network.

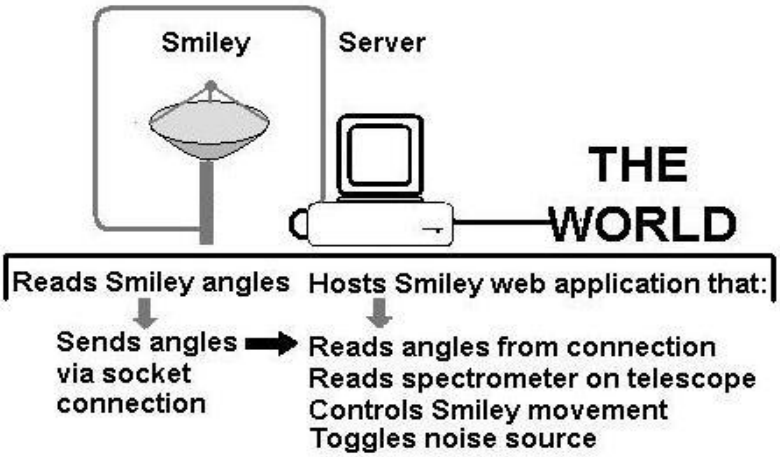


Figure 2 – New Smiley Setup

SynchroServer Modification

Before examining the source code for SynchroServer, it was important to note the old card used an ISA bus and the new card uses a PCI slot. This difference affects how SynchroServer interacts with the card. The old version used hardware addressing explicitly to access the card, whereas the new version uses functions imported from a library distributed by DDC to initialize and read digital angles from the card. Modifying SynchroServer to work with the PCI card boiled down to finding source code that interacted with the card and designing code that would fulfill the same functions using the library.

Since the card is connected to a physical device that causes real-time changes in the data stored in the registers, the state of the registers must be frozen before the program reads it to avoid retrieving fuzzy data. “Inhibiting” a register means to freeze its state until it's been released. These registers are represented as “channels” on the card, each connected to an encoder on the telescope's axles. The two channels contain data about the telescope's azimuth and elevation. The old version of SynchroServer took many samples by doing an inhibit, read, then release cycle until it had a collection of sample readings then averaged them. This function is meant to return the horizontal and vertical angles in degrees in such a way they can be easily converted to azimuth and altitude, but encoders only return angle values relative to their reference angle. The physical reference angle the encoders use is not correlated to the zeros for azimuth and altitude in the sky, so an offset must be added to the physical angle to get the location at which it is pointed. In the old version of SynchroServer, the offsets for the angles

were hard-coded in the program itself and changed by modifying the project and rebuilding. The newer version of SynchroServer reads these offsets from a configuration file so the project won't have to be rebuilt any time the offsets need to be changed. These offsets are added as a final step, and then the resulting angles are returned from the function.

The new version of SynchroServer uses functions from the DDC library to read the binary representation of the angles from the inhibited card once before releasing it, convert the angles to decimal, and add their corresponding offsets. After some consultation with knowledgeable members of PARI, I decided averaging numerous samples is not necessary because the precision of the angle used by the web application is 1/100th of a degree, which is larger than any fluctuation seen in the angle data from the card. In other words because the precision is cut down to 2 decimal places before being sent to the application, any benefit of averaging is lost.

Deployment

Once the modifications to SynchroServer were completed and tested, the web application was configured and deployed on the test deployment computer after moving it down to the Smiley Cage. The reason we used a test deployment machine was so the machine we eventually used would have a fresh installation of Windows and contain only the software necessary for the web application to work. After confirming all software was installed correctly and all peripherals were connected, we booted up the website and were able to confirm the web application was able to access all hardware necessary to control the Smiley telescope. After this, we installed all necessary software on the new, official computer and configured it to host the Smiley web application on the web. On the 23rd of July, the new setup went live and by the 30th all bugs found during user-testing had been eliminated and the project designated a success.

Calibration Feature Project

For my second project I modified the control applet in the Smiley web application to include a button that accesses a Remote Power Booster (RPB+ unit from Western Telematic) via a serial connection and commands it to turn the plug to which the noise source used in calibrating data collected from the spectrometer is connected on or off.

The most challenging part of this project was negotiating the interface between hardware specifications (real-time delays and commands accepted) and the GUI. The button is designed to toggle between “ON” and “OFF”, reflecting the current state of power to the noise source. One issue complicating this process is that the RPB requires a delay of around 3.5 seconds after receiving a command before it can accept another one. In other words, if the user mashes the button repeatedly it cannot be assumed the power will turn on or off, which makes matching the label of the button to the actual state of the device slightly more complicated than simply switching from “ON” to “OFF” and vice versa any time the button is pressed.

My first solution to this problem was to hard-code a delay so the user could not send a command before the RPB was ready. However, this resulted in delays that were longer than necessary to avoid sending commands prematurely. After researching and testing methods of reading output from the RPB, I changed the feature so all commands sent to the RPB went through a driver that checked output from the RPB for a prompt before they are sent. This allows the user to send the command as soon as the RPB is ready.

Since the noise source affects the data gathered by the spectrometer, it is of vital importance to make sure the RPB plug is off when a session starts to avoid collecting false data. This new feature sends a command to turn off the plug both when a control panel session is started and when the control panel session ends.

Conclusion

Over the course of my internship I completed these two projects, helped out briefly with the Duke TIP program in June, and gave impromptu explanations of my internship to the many groups of fine visitors we receive at PARI. When my internship was completed, the Smiley web application that is accessible through PARI's website was hosted on a single machine in the Smiley Cage and had a brand new feature that allows the user to toggle a noise source. These improvements will benefit those who use the Smiley web application, and I'm pleased both projects went well.

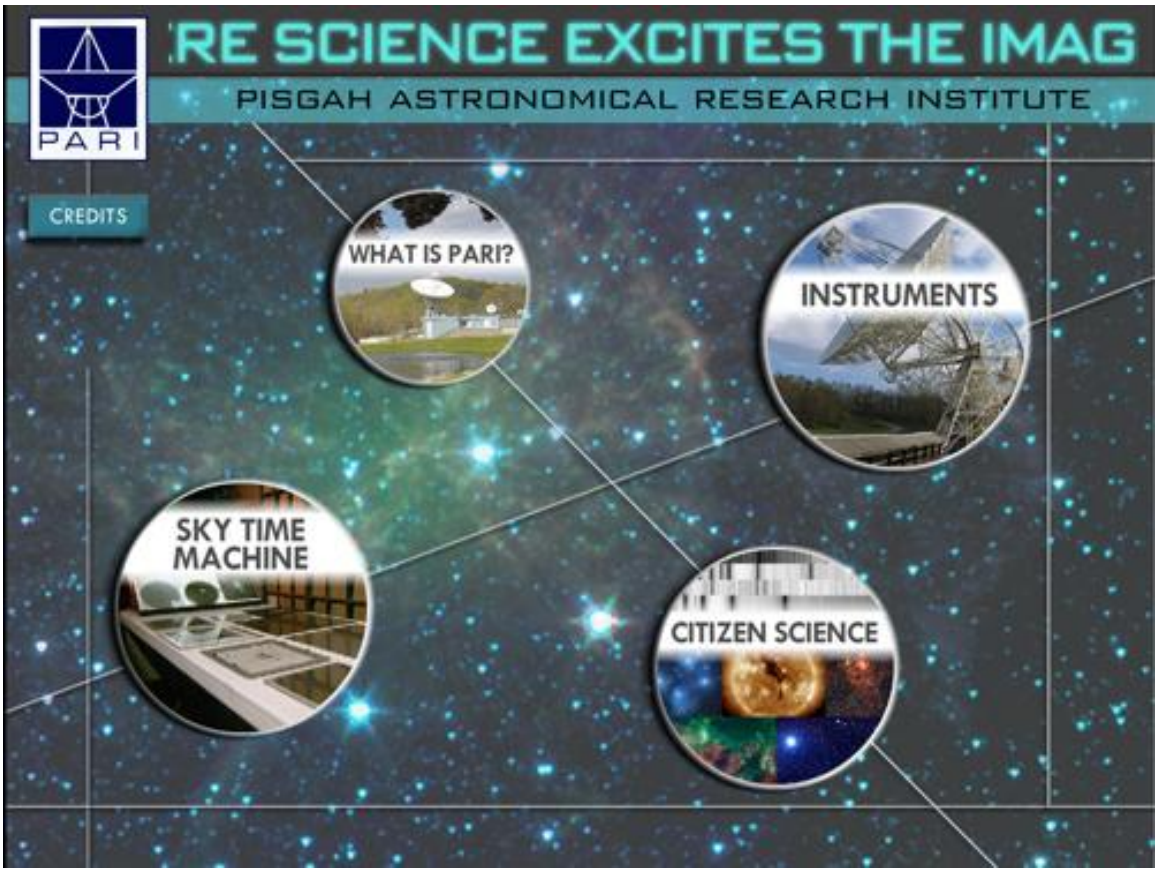
Acknowledgments

Many people made this internship a blast. My sponsor, Bob Hawkins, the Vice President of North Carolina Operations at EMC, made this experience possible. From the staff at PARI I'd like to thank Michael Castelaz, Lee Rottler, Christi Whitworth, and Lamar Owen for their support, advice, and encouragement all throughout my internship. Thanks to Menelik Zafir and Emma Taylor, my fellow interns, for keeping me sane in the middle of the forest with their company. Also thanks to previous interns Michael Schneider and Alexander Ross for being available to offer their input and clarification on questions pertaining to the projects they worked on at PARI.

DEVELOPMENT OF AN INTERACTIVE KIOSK APPLICATION

REBEKAH DAVID
UNIVERSITY OF NORTH CAROLINA AT ASHEVILLE
NSF NSDL DIGITAL RESOURCES & SCIENCE EDUCATION INTERN

There is a wide variety of research and education projects, as well as data and image collection taking place at Pisgah Astronomical Research Institute. The development of an interactive kiosk application would facilitate the presentation of this information to a wider audience, including visitors to the North Carolina Museum of Natural Sciences (NCMNS) in Raleigh, where the new Nature Research Center wing hosts an exhibit showcasing PARI. Additionally, this application could be installed onsite at PARI for site visitors to explore. This project has consisted of two main phases of development, both of which included content creation, design, coding and packaging the application. My primary goals were to develop a robust application based on usability testing and strong code; to create an attractive interface that is easy to use for a diverse range of users; and to develop content that engages the user and makes PARI's research, instruments and various pursuits understandable and interesting regardless of the user's scientific background.



PHASE I

Phase I of the kiosk application development occurred in March 2012 and resulted in the first basic version of the kiosk application. Phase I was completed at the beginning of April 2012, at which point the application was deployed at the NCMNS in time for the grand opening of the new wing. Version One of the kiosk application featured five subsections of content:

- *"What is PARI?"* – "To the Stars and Beyond" video, bulleted information about PARI's history, instruments, and recent/ongoing projects
- *"The Sky We See"* – opens the PARI Sky website in a custom browser window
- *"The Night Sky: Past & Present"* – "The Night Sky: Past & Present" video
- *"Sky Time Machine"* – interactive module showcasing the Astronomical Photographic Data Archive (APDA)
- *"Classify Stars"* – opens the SCOPE website in a custom browser window

At the time of the grand opening, the sections that opened websites were not functioning due to complications in the way the ActionScript code functioned on OS X versus Windows, but this problem was resolved about one week later. The custom browser windows were removed during Phase II, and the application now functions identically on both operating systems.

TECHNICAL CONSIDERATIONS

The application would need to be a stand-alone application that could be deployed on a computer using the Windows 7 operating system. Although this would be the first application I had developed, Adobe Flash seemed the obvious choice for a development platform, since it allows for easy development of attractive graphical interfaces with minimal programming knowledge (I have much more experience in the design aspects than the programming aspects of interactive design). After a bit of research, I discovered I would need to develop the application in Flash, and then package it in Adobe AIR. I had no previous experience with AIR, and this would lead to some of the greatest technical challenges in the project (see the **CHALLENGES** section for more details).

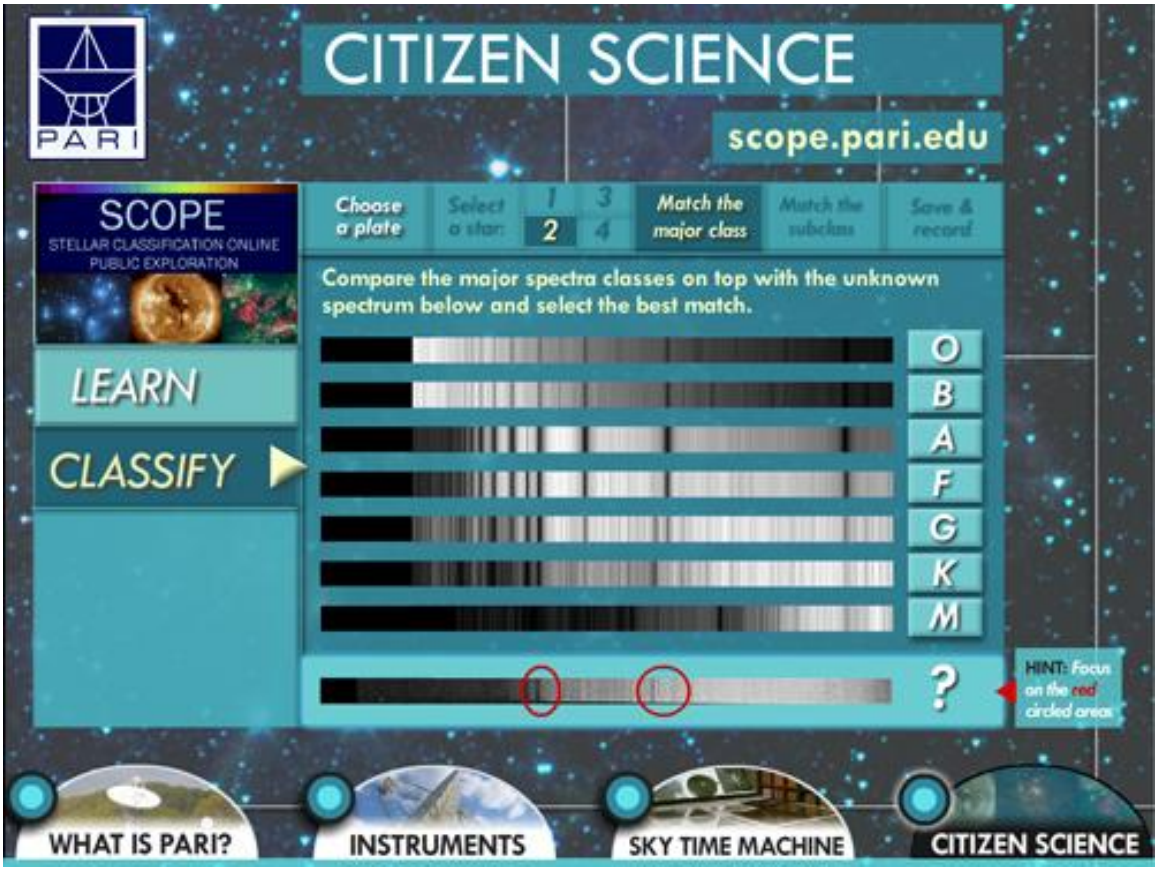
PHASE II: PLANNING

Phase II of the development project began in June 2012, with the goal of expanding and refining the content. The first few days of Phase II were spent brainstorming ideas for new content and needed changes to the existing content, as well as developing a revised information hierarchy and navigation structure. This process involved ongoing discussions with staff, thorough exploration of the content on the website (www.pari.edu) and extensive sketching of the graphical and structural layout of the possible additional content.

The final outcome of this investigation was a decision to focus on the development of an interactive module for the SCOPE (Stellar Classification Online Public Exploration) project (to replace the link to the actual SCOPE website—
see the **PHASE II: DEVELOPMENT—SCOPE SECTION** for more details), a section focusing on the instruments and tools at PARI, refining the text in the "Sky Time Machine" section, restructuring the navigation to accommodate the new content, and, if time allowed, expanding the "What is PARI?" section to include more information about the history and research projects at PARI.

PHASE II: DEVELOPMENT—SCOPE SECTION

Version One of the application already featured a section that opened the SCOPE website, but there were several problems with this setup. First, the Webkit engine that Adobe AIR uses to render webpages distorted the text, making the site very difficult to read. Second, the SCOPE website uses PHP or Java (the user can decide), with most clicks within the Classification module opening new browser windows. The browser interface I had to create within the Flash application would not accommodate opening multiple browser windows, and integrating the PHP or Java processes would necessitate working with someone to manipulate the actual code on the website. Finally, I decided that the structure of the existing SCOPE website would make it difficult for the casual museum visitor to understand and start using the site during a visit to the PARI exhibit at the museum. Therefore, I decided to develop a module within my application that would simulate the process of learning about and classifying star spectra in a more clear and straightforward way.



I divided the SCOPE simulation into two sections: "Learn" and "Classify". The "Learn" section featured simple question-and-answer subsections about star formation and classification, such as "What are stars made of?" and "How can stars be different from each other?" This is intended to provide some context for the "Classify" section, in which the user can select one of four star spectra from a plate (similar to the way the actual SCOPE website is set up), then go through the process of choosing the most closely matching star class. I was able to conduct several usability testing sessions for this section, which I believe substantially improved the ease of use and clarity of the classification process.

PHASE II: DEVELOPMENT—INSTRUMENTS SECTIONS

After the SCOPE section was complete, I began to gather content for the "Instruments" section. The time required development of this section would far exceed my estimations, due to the complications in integrating live data feeds, as well as in developing content that adequately explained the significance of the data.

After reviewing the content on PARI's website, exploring the directories in the onsite server and having discussions with staff about the most important instruments and tools utilized at PARI, I decided to develop nine subsections of Instruments, split into three categories as they are on the website:

RADIO:	OPTICAL:	EARTH:
Radio JOVE Antenna	PARI Sky Camera	Weather Tracking
26-m East & West Telescopes	NASA All Sky Fireball Cam	Earthquakes*
Smiley Telescope	Solar Telescopes	Geomagnetometer

*The EARTHQUAKES section would include information on the Seismometer and the Plate Boundary Observatory.

The first step, after deciding on the content sections, would be to determine what kind of content I would need to gather and/or develop for each instrument, and how to display this information cohesively for nine different instruments. I decided to split up each set of instrument information into four sections that changed only slightly depending on the instrument:

- *What is it?* – A basic description of the technical specifications and/or its setup
- *What's it used for? / Why is it important?* – A description of the significance and/or use of the instrument and its data
- *Live data/views* – Live webcams, live data feeds pulled from the website, etc.
- *Photos/Best hits* – Photos of the instrument or people using it, highlights from the archives of the instrument data feed

PARI
Instruments
RADIO
OPTICAL
EARTH SCIENCE
26-m East & West Telescopes
Radio JOVE Antenna
26m East & West Telescopes
4.6m Telescope (SMILEY)
What is it?
What's it used for?
Live views
Photos
26-m East Telescope
26-m West Telescope
WHAT IS PARI?
INSTRUMENTS
SKY TIME MACHINE
CITIZEN SCIENCE

PARI
Instruments
RADIO
OPTICAL
EARTH SCIENCE
Weather Tracking Stations
Weather Tracking Stations
Earthquakes
Geo-magnetometer
Weather at PARI
How is it used?
Live feeds
Lightning detector
Enhanced image (enlarge)
Raw image (press to enlarge)
WHAT IS PARI?
INSTRUMENTS
SKY TIME MACHINE
CITIZEN SCIENCE

I gathered much of the content from the PARI website—nearly all of the text and most of the images. The rest of the images were found on the onsite server.

PHASE II: NAVIGATION AND INFORMATION HIERARCHY

After restructuring the content, I had to decide how to restructure the navigation menus and group the content. Since the SCOPE project would be featured in the simulation section (which I renamed "Citizen Science"), the "Classify Stars" section was no longer necessary, so I removed it. The PARI Sky instrument would now be included in the new "Instruments" section, so I removed the "The Sky We See" section. I also decided to include the "The Night Sky: Past & Present" video within the "Sky Time Machine" section, since it is largely about APDA as well. The new navigation features four sections:

- *"What is PARI?"* – No major changes from Phase I
- *"Instruments"* – Showcasing 9-10 different instruments at PARI
- *"Sky Time Machine"* – "The Night Sky: Past & Present" video and an interactive module showcasing the Astronomical Photographic Data Archive (APDA)
- *"Citizen Science"* – SCOPE simulation module

CHALLENGES

PHASE I: The first major technical issues I encountered were in Phase I, concerning how to package the application in Adobe AIR for easy deployment. There is an AIR packaging function built into Flash, but I encountered a number of errors while using this function. As mentioned before, the first version of the application included two external custom browser applications to open to PARI Sky and SCOPE websites. I was able to package the AIR application within Flash at first, and it worked well in OS X. However, upon testing in Windows 7, the browser windows would not open. After many hours of Internet research and trial and error, I determined that the problem was the file path to open the external browser applications; Windows required a different file path than OS X. After this problem was solved, I was no longer able to package the application within Flash for some reason. After more research, I learned how to use the Adobe AIR SDK (Software Development Kit) at the command line, which I used for packaging from then on. After further errors and even more research, I learned that Adobe AIR has problems packaging applications that include media files that exceed a certain (undefined) size. I compressed the two videos that were included in the application, which solved the problem, and I finally was able to successfully package and deploy the application.

PHASE II: In the SCOPE simulation "Classify" section, I had to find four example spectra that were distinct and that matched, relatively closely, the standard spectra for its appropriate class. Since most spectra within SCOPE differ quite a bit from the standard spectra, and learning the subtle differences that allow you to distinguish between classes is relatively challenging, this was a difficult task. I also had to spend a bit of time resizing and refining the images in Photoshop to get them to align properly with the standard images in my Flash application; the SCOPE website does this automatically through Javascript code.

In the “Instruments” section, I had to learn how to integrate live data feeds from the website into the AIR application. This is pretty simple ActionScript code that calls the URL and dynamically displays it at the specified coordinates of the application. This was a little time-intensive to deal with once I had to develop a new file for 16:9 display ratio (see next paragraph). I also encountered problems with the dynamically called images and videos, which sometimes remained on the screen after clicking through to another section of the application. I had to add additional ActionScript code to unload these items from each frame that a user could possibly go to after the frame with the item. This has possibly added a lot of weight to the file size and could potentially be optimized at a later time.

I also encountered problems trying to deploy the application on the touch screen monitor at PARI. It is a 21-inch monitor that can display in 4:3 or 16:9 ratio, but in the 4:3 ratio the touch sensor is not calibrated properly and cannot be fixed. In the 16:9 ratio, the application was stretched, no matter how I edited the actual size within Flash. I had to go into the advanced display settings of the monitor and activate a certain display resolution that was not set up, and I still had to create a new 16:9 application file that is separate from the 4:3 one on display at the museum in Raleigh. A better solution than two separate files would be desirable, but not a priority at this point.

Near the end of Phase II development, my main .FLA file became corrupted and a few .DAT files had to be removed for recovery. This deleted many graphic assets in the application library, which had to be reconstructed from scratch. I believe this event caused the file problems that endure as of this writing.

The application, once packaged in AIR, is extremely laggy. The “Sky Time Machine” in particular is unresponsive for up to a minute following a button press. I have been researching optimization of AIR applications and Flash files, but have not yet found a solution. Various sources suggest that excessive “Event Listeners” in the ActionScript 3 code, which I use to create functions for all my buttons, can cause major slowdowns at runtime. This is how I learned to handle buttons, but I am aware that there are other, more efficient ways of creating buttons and their functions using more complex ActionScript, so the next step for me is doing some tutorials to learn how to do this and editing my code in the application.

POSSIBLE FUTURE IMPROVEMENTS

If time allows, I hope to be able to spend some time further improving the usability, content and efficiency of the kiosk application. First of all, the highest priority will be to troubleshoot and optimize the entire application for speed and file size. In its current state, it is far too slow to respond and occasionally freezes for up to a minute. As mentioned before, I believe these problems can be resolved by removing excess ActionScript code and duplicate functions, and by using code instead of the Flash GUI to dynamically instantiate the various image assets in the file. This process may take a few weeks, as I will need to do some tutorials on ActionScript to get a better grasp on how this works.

I would also like to do more usability testing on the entire application after the above problems are resolved. The usability testing I conducted on the SCOPE simulation section was very

insightful and led to necessary changes I could not have determined on my own. It would be incredible to develop some kind of click-tracking that would generate statistics on how users navigate through the application, how long they spend in each section, on what section they stop using the application, etc.

I had also intended to further develop the "What is PARI?" section, adding information and images about the history of PARI, including a more interactive module like the one in the "Sky Time Machine" section, and so on. I did not have sufficient time to complete this task.

Other possible improvements include a Spanish version of the kiosk application, accessibility features and a way for PARI staff to update text remotely.

SUMMARY

I am very satisfied with the improvements I was able to make on the first version of the kiosk application I had developed before my internship began. I feel that the new content and design express the significance of PARI's research and other undertakings, in a way that is accessible to a public that may or may not be familiar with the more technical aspects of astronomical research. I went to great lengths to include simple and clear information about the importance of the work done at PARI, and I am happy with the outcome of these efforts. Although improvements need to be made on the code to optimize the functioning of the application, dealing with this situation has taught me an important lesson about planning more carefully in dealing with complex application development; I probably could have prevented this problem by better managing the numerous graphical assets included in the file, from the beginning. After these improvements are completed, I will be excited to see the application installed onsite at PARI, as well as in the NCMNS museum in Raleigh. I believe it will function as a good representation of PARI to museum visitors and other users.

A PHOTOGRAPHIC SURVEY OF THE MESSIER OBJECTS

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Abstract

During the summer of 2012, we used the Furman/PARI 14-inch telescope to image as many of the objects originally catalogued by Charles Messier in the 18th century. We were able to successfully photograph 99 out of total 109 Messier objects. This survey allowed us to test the imaging capabilities of the telescope to observe deep sky objects of differing size and visual magnitude.

I. Procedure

The Furman/PARI telescope consists of a 14-inch Celestron Schmidt-Cassegrain OTA mounted to a Paramount ME, located at the Pisgah Astronomical Research Institute. Images were taken with a SBIG ST-2000 CCD camera mounted to the telescope through a Fastar lens assembly, which moves the focal point of the telescope from the Cassegrain focus to a position in front of Schmidt corrector plate. The Fastar changes the focal length to diameter ratio from 10:1 to 2:1, thus increasing the size of the imaging plane and reducing the exposure time for deep sky objects from several minutes to 30 – 60 seconds. Focusing the telescope is still achieved through manual movement of the primary mirror.

The observations were conducted mainly between the hours of 10:00 PM and 4:00 AM local Eastern Daylight Time, limited by cloud cover, dew point (condensation on optical surfaces), and light pollution from the Moon. Needless to say, with all the limiting factors, we still had a few nights suitable for observing the plethora of objects cataloged by Charles Messier in the 18th century. Messier was in search of comets, but when he observed objects in the sky that were not, he cataloged them so as not to continually mistake them as comets. He himself had little interest in observing the 109 heavenly objects which we sought out to completely capture in a single summer.

In hindsight, we did not properly approach our daunting task. The first night that we were able to observe and photograph these objects, we were so fascinated by the novelty of capturing pictures of galaxies, nebulae, and star clusters that we neglected to think about the order the objects should have been observed, and so, missed a few Messier objects in our survey. Instead of taking pictures of the objects that were first to set, we sought after the glorious spiral galaxies and famous nebulae that resulted in magnificent photos. This may have been what motivated us to continue on our exhaustive quest of imaging all of the Messier objects.

The actual process of taking the photographs was not very intricate. We could do nearly all of the work remotely from the PARI control room. We would first open the roof, and then establish a connection to the telescope using the The Sky program by Software Bisque. This program allowed us to look up a catalogue position and slew to the desired Messier object. We would then open the camera program, CCDOPS by SBIG, and select the exposure time and filter that we intended to use. For every image, we used a clear filter, and our exposure time depended on how bright the object was. A faint object like a distant nebula required a long exposure, at least 60 seconds, in order to get a clear picture. Large globular clusters needed only 30 seconds or less. In comparison, the planet Saturn required just a fraction of a second because of its brightness.

We did encounter a few hindrances in our quest. Frequently, the roof would not remotely open or close, and thus we would have to drive up to the Optical Ridge to manually open it. We also ran into the problem that the telescope would get stuck in a position and would not slew away from it. This was a less simple problem to fix: we found that the declination knob was over-tightened, and loosening it seemed to remedy the situation. We also had to clean off the main mirror at the beginning of the summer because it had collected a significant amount of dust. Overall, the procedure was fairly smooth and uneventful, which allowed us to be productive with our limited time.

II. Results

Over the course of about 10 different nights, we were able to accumulate pictures of 99 distinct Messier objects. A select few of these are displayed in the figures below, but they do not properly reflect the actual work required, including nearly sleepless nights and a high level of focus. During the process we learned much about how to remotely operate a computer controlled optical telescope. We also learned in more detail about the different types of objects in the sky, and were able to observe the unfathomably large distances between the earth and these distant objects. We still have more Messier objects to image. We were unable to collect images of 10 objects, and we plan to obtain these photographs some time during early Spring of 2013, when they are visible in the night sky.

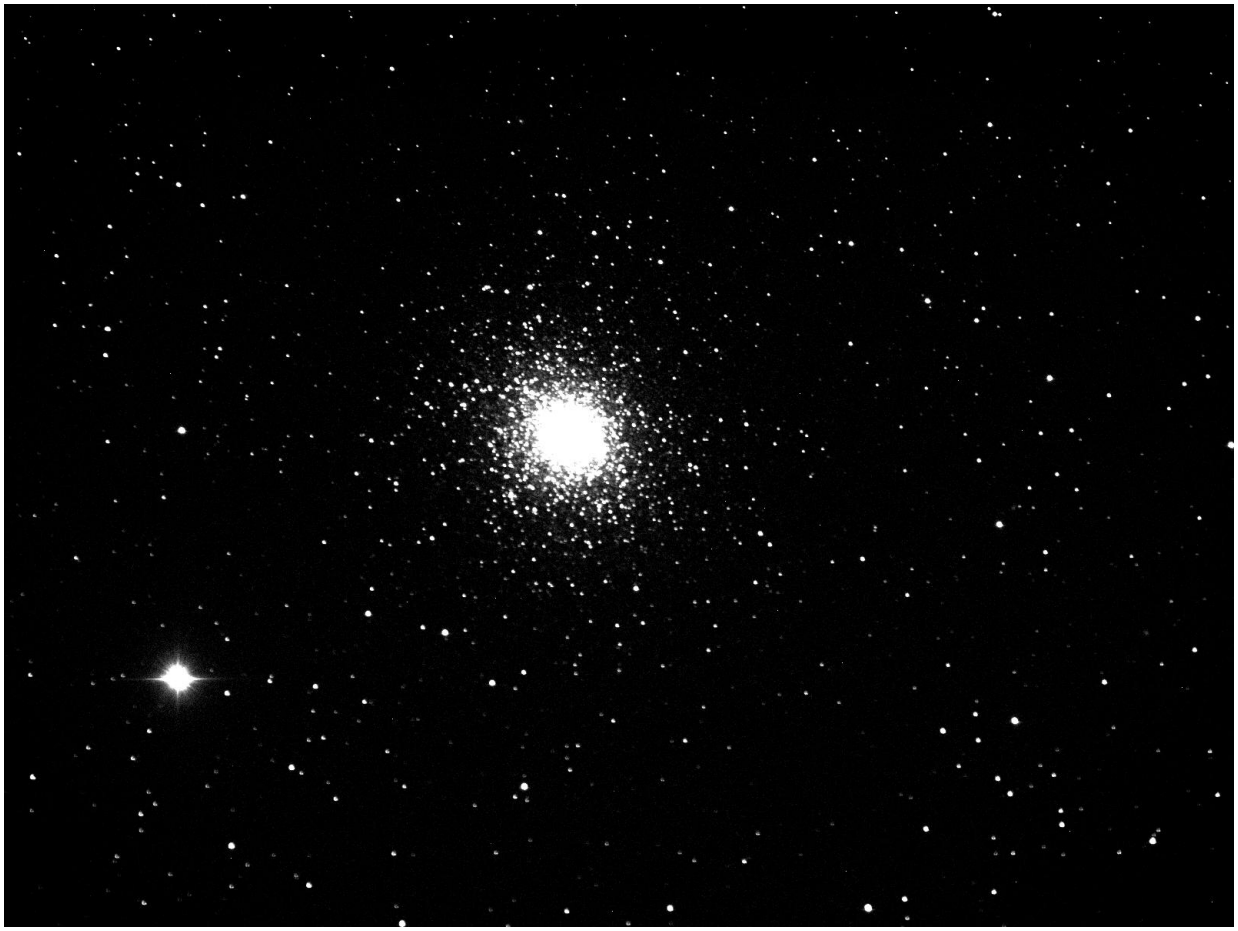
III. Acknowledgements

R. Picardi and L. Smith acknowledge support from NSF grant AST-0908266. We thank the staff of the Pisgah Astronomical Research Institute (PARI) for their hospitality and support during our visit. We also thank Dr. Michael Castelaz and Dr. David Moffett for their invaluable help. PARI is a not-for-profit foundation dedicated to providing hands-on education and research opportunities for a broad cross-section of users in STEM disciplines.

M51: The Whirlpool Galaxy – Two colliding spiral galaxies

M81 and M82: A spiral and irregular galaxy

M8: The Lagoon Nebula



M5: A Globular Cluster

M101: Spiral Galaxy

COMMISSIONING OPERATIONS FOR THE DIRV INTERFEROMETER

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I. Objective

Our objective this summer was to work on successfully commissioning the DIRV interferometer at PARI. We anticipated that this would not be as simple as using the two telescopes conjointly and immediately begin observing results, so inherently part of our objective was to fix any issues that would lead to improve the functionality of the interferometer. The largest obstacles that we had to overcome were tracking issues, a faulty pointing model, receiver focus, and the unconventional construction of the correlator rack. These hurdles quickly became part of our daily routine and thus must be included in the list of what we anticipated completing.

II. Commissioning Exercises

A. Tracking

The very first procedure that we performed on the telescopes was diagnostic in manner. After our arrival at PARI and were familiarized to the equipment, we were immediately presented with the problem that the telescopes were unable to track objects for extended periods of time. Much of the rest of our first week was spent confirming that this was true. The DFM TCS (telescope control software) was failing to properly track targets in R.A. and Declination. We observed by eye the amount each telescope would drift from its designated sidereal position at different angles in the sky by using a stopwatch to record each telescope's drift in two-minute intervals. We performed numerous tests for many hours and with little correlation or repeatability between tests. It did seem as if as the zenith distance increased, so did the error, but there was no conclusive pattern in the data for us to properly create a model to fix this error. Generally, we observed about a 0.5 arc-minute/minute drift in RA, but there was no pattern in DEC drift. We became quickly comfortable operating the 26-meter telescopes from their control stations in the Cline Building, which proved to be a helpful and necessary skill later in our work. This tedious work also allowed us to prove conclusively that there was no easy solution to the tracking error, and that the DFM TCS programmed tracking rates were not properly set.

It was not until the following week, when the UNC-Asheville research group arrived that we were able to make progress on fixing the tracking problem. They were able to program the telescopes to continually slew back to the designated source, and this kept them in a very acceptable range of error. This allowed us to continue with our efforts to find sources in the sky and be able to point to them with reasonable levels of assurance that we will actually remain where we believe to be.

Figure 1: 26 East DFM Repeater and OCU. The control software is DFM's TCS program. The telescopes can be commanded to a target RA-Dec or X-Y position, and manually controlled through the use of a hand paddle.

B. Drift Scans and Focusing

After finding these sources, we diagnosed the problem that the telescopes were out of focus because of our drift scans. We were able to point at a source and use the power reading programs to indicate when we had reached the maximum level of power. We then would move the telescope a few minutes west of the object and turn tracking off so we could watch as it drifted through the field of view. We were able to observe the power rise to a peak and then fall back down to a baseline. We performed two drift-scan tests, one on the moon and one on Cas A, and by the width of the slope we were able to conclude that both telescopes were out of focus, and each had beam widths that were approximately 28 arc-minutes wide. This error is significantly large when you consider that at S-band, their beam widths are only supposed to be

18 arc-minutes across when in focus. As of this report, the telescopes have not yet been focused. The process of focusing will require a sequence of feed actuation followed by drift scans, or a careful observation of the incoming power level as the feeds are moved into their focal points.

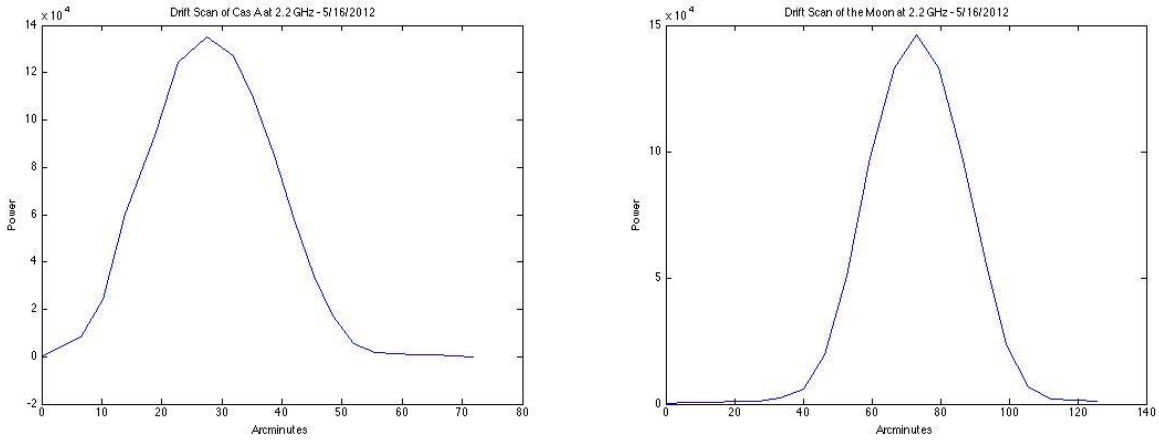

Figure 2: Drift scans made with the IBOB Correlator attached to 26 West telescope at S-band. Shown are scans of Cas A (left) and the Moon (right).

C. Correlator Rack Modifications

Another problem that needed to be addressed was that the correlator rack was not efficiently organized. There were unlabeled wires and the correlator was installed sideways, making it very difficult to attach cables to it. We rearranged the entire rack so that the correlator was easier to access. We also installed a self-terminating (50-ohm) patch panel that allows us to easily switch our inputs from S-band to X-band, and from 26E to 26W, without having to dig through the back of the rack. We then attached brand new cables and labeled them based on the information they carried. We also installed the wideband detector which allows us to observe detected receiver output power. During all this we were able to learn a lot about the inner workings of the rack and follow the information through the passage that it takes. We were able to understand the use of mixers and attenuators so that if we were not seeing the proper results when making observations, we were much more capable of fixing the problem quickly and efficiently. We even learned more simple but helpful things, such as the different types of cable connectors and the reason why the rack was ordered how it was.

Figure 3: Correlator rack after modifications

D. DIRV Interferometer

Radio interferometry is the use of multiple radio telescopes in congruence to take measurements. In essence, the telescopes work together to synthesize a telescope with a much larger aperture, yielding a resolution far greater than that of a single telescope. An interferometer's resolution depends on the distance between the telescopes. Another advantage of an interferometer over a single telescope is that it can detect weaker sources than originally was possible, a good example of synergy. At PARI, we have access to two 26-meter radio telescopes, which on their own have the ability to observe sources at resolutions of 18 and 5 arc-minutes at S- and X-band respectively. With a base length of 350 meters, the DIRV interferometer has resolutions of 1.3 and 0.4 arc-minutes at S- and X-band.

Our work toward the goal of making interferometer observations began this summer by simply ensuring the pointing accuracy of each of the 26-meter telescopes. This is vital for the overall accuracy of the interferometer, and is still a work in progress (see next section). Our first actual tests of the interferometer provided helpful feedback. When we would point both telescopes toward the same position and collect data through the IBOB correlator, we did not

notice that the two were working together to form a more accurate instrument. Instead, errors in focusing and pointing models caused our results to be incoherent.

In our next attempt at using the DIRV interferometer, we made sure that both telescopes were at the peak position of the bright radio source, Cygnus A. When we viewed Cygnus A with both dishes and collected the data through the IBOB, we were able to clearly observe evidence of interferometric fringes (see Fig. 4, 5 and 6), where the signals from the two telescopes were combining constructively. This was an exciting discovery, and the first sign that we have a working interferometer at PARI.

We proceeded to make more observations on other sources, but with less fortunate results. The only other sources that we were able to record were much weaker than Cygnus A, and thus did not have fringes that were as distinct. There were a few sources with fringe-like patterns, but most of the other sources had no observable fringes from their data collection. The UNC-A group is making modifications to the correlator program to provide longer integration times to detect fringes from weaker radio sources.

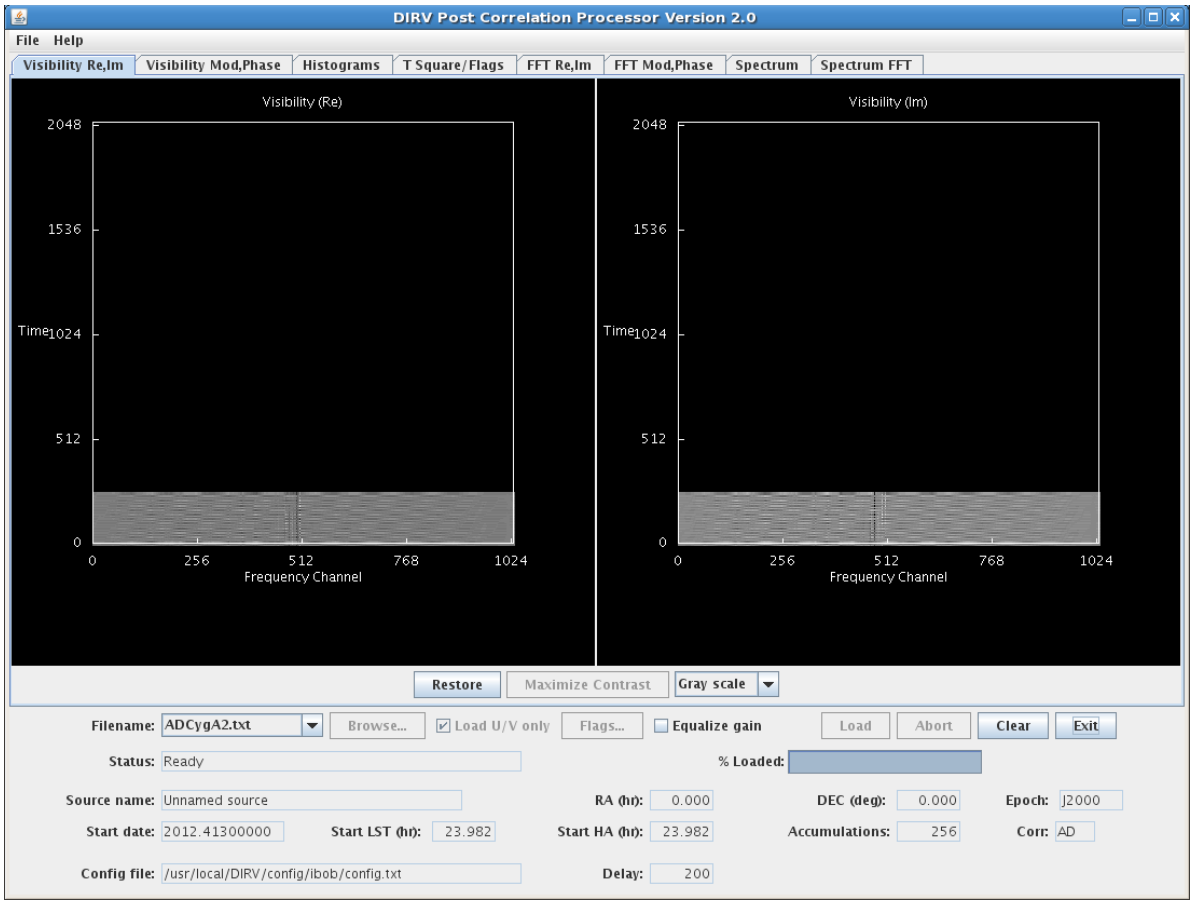

Figure 4. DIRV IBOB Correlator Visibilities (Real and Imaginary) of Cygnus A at S-band.

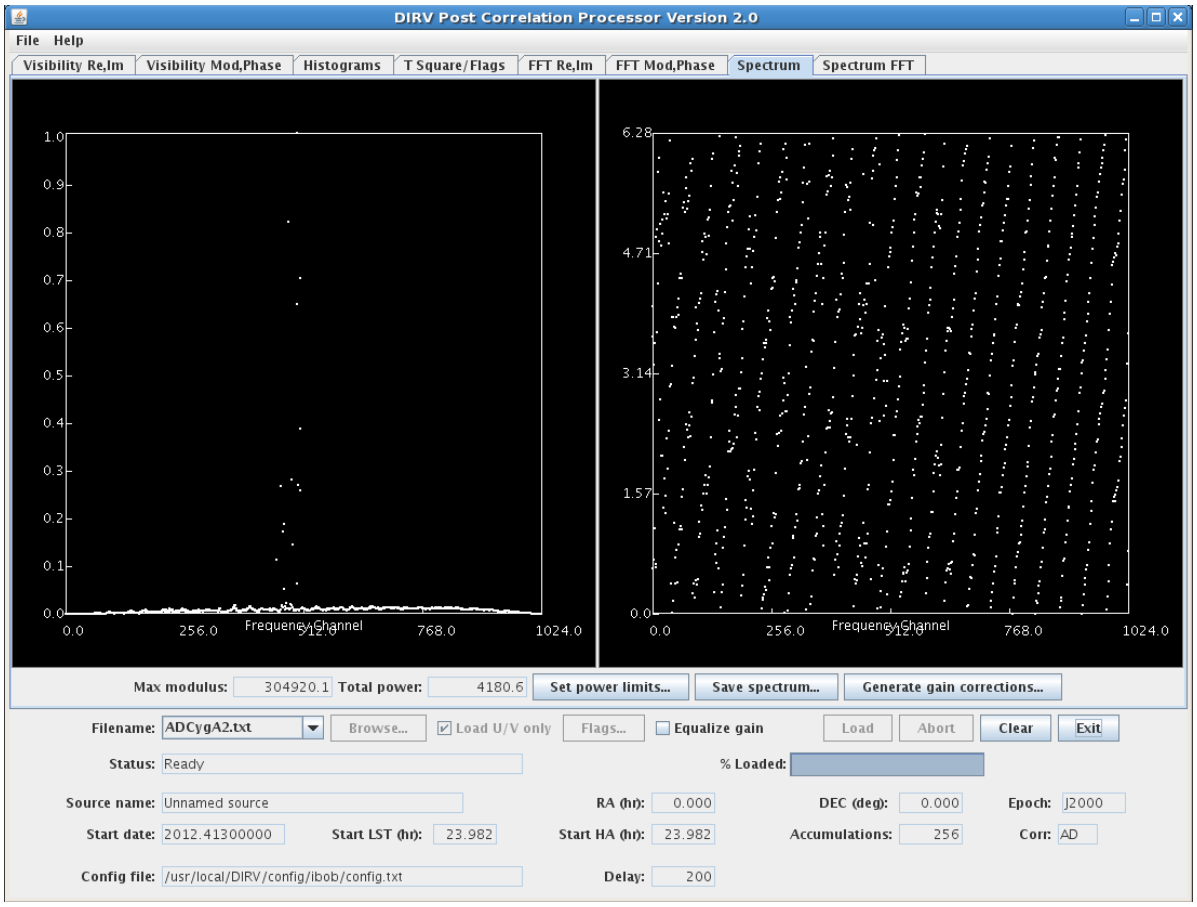

Figure 5: Plots of DIRV's cross-correlation spectral power and phase of the same observation shown in Fig. 4. Phase wrapping can be seen in the right panel due to a frequency-dependent phase delay when the interferometer is on source.

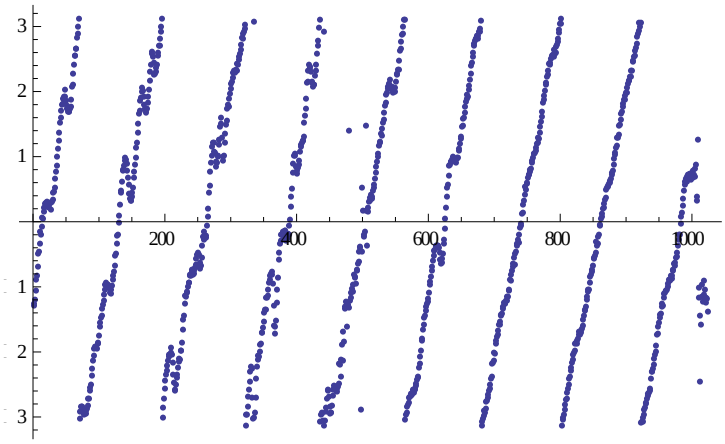

Figure 6: Fringes after being compiled in Mathematica

E. Pointing Model:

The pointing model is vital to having functioning radio telescopes. It ensures that when you slew to a position, that where you are is indeed where you intend to be. Because resolution of an interferometer is higher than that of a single telescope, a good pointing model is essential

for a successful interferometer observation. A faulty pointing model, like the one that we have on both 26 East and 26 West, will cause the interferometer to miss the source completely. The majority of our work for the second half of our time at PARI this summer was mainly dedicated to improving the telescopes' pointing model.

We noticed very early on that when we would slew to a point, our desired location was usually tens of arc-minutes away in the sky. The process of finding the peak position of a radio source was tedious, but we were able to become much more efficient in our pointing observations as the summer progressed. We began by trying to find positions by performing individual drift scans, but this quickly proved to be too time consuming. We then used a computer program that gave us one power reading per second (output from the IBOB's autocorrelator), and we would hand paddle the telescope until we felt that we reached the apex of power. However, this style was quickly replaced by the use of the Wideband Detector and oscilloscope, which integrated continually, allowing us the ability to much more efficiently find the position of bright radio sources. This was necessary because we needed to record hundreds of points before the end of the summer. This quantity is essential to have an accurate model and to notice real and helpful patterns in the data.

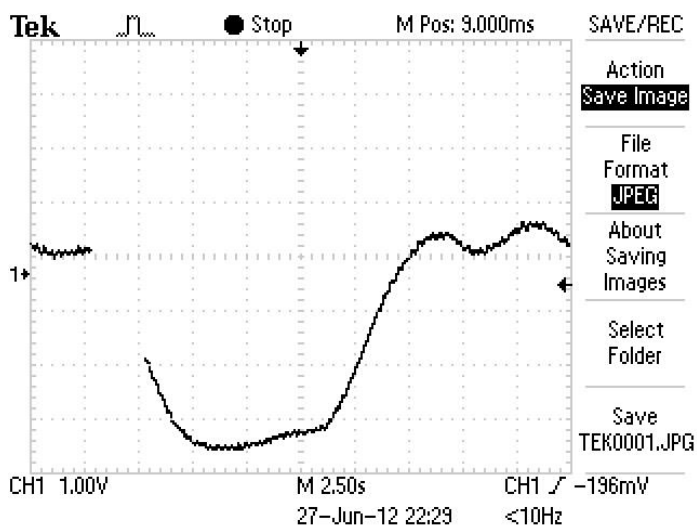

Figure 7: Screen-shot of the oscilloscope we used to peak radio sources

Each time we made pointing observation, we would to slew to the accepted catalogue position of a radio source (see Table 1 below). We would then adjust the oscilloscope's gain so that the power reading was in our field of view, and make sure the attenuators were set so that the power entering the oscilloscope was at an observable level. We would then hand paddle around the source and watch as the power levels rose and fell until we found the pinnacle, and then we would save the position data on the DFM control computer. This would save not only our current position but also our intended position so we can easily observe the offset, which is the essential in compiling pointing data. We also recorded the hour angle of each point, to see if it pointed differently in different parts of the sky. Another variable we needed to be conscious of was that we needed a large range of RA positions for points as well, to ensure we try to capture the whole sky and have the most complete data possible. Plots of these data for each telescope can be found in Fig. 8 and 9.

Table 1: Coordinates of radio sources used for pointing observations

Source	RA 2000 (h,m,s)	Dec 2000 (d,m,s)	Flux Density (Jy)
Cygnus A	19 59 28.3	40 44 02	~1000
3C433	21 23 44.8	25 04 18	~9
Cassiopeia A	23 23 24.0	58 48 54	~2000
3C20	00 43 09.2	52 03 34	~9
3C48	01 37 41.1	33 09 32	~13
3C84	03 19 48.2	41 30 42	~10
3C98	03 58 54.5	10 26 02	~9
3C111	04 18 21.3	38 01 36	~13
3C123	04 37 04.4	29 40 14	~38
Crab Nebula	05 34 31.0	22 01 00	~1240
3C147.1	05 41 42.6	-1 54 17	~50
3C147.0	05 44 06.0	51 01 00	~17
3C196	08 13 36.0	48 13 03	~11
3C219	09 21 08.7	45 38 58	~7
3C231	09 55 52.2	69 40 49	~6
Virgo A – 3C274	12 30 49.4	12 23 28	~150
3C286	13 31 08.2	30 30 33	~14
3C295	14 11 20.6	52 12 21	~17

There are two different bandwidths that we are capable of observing with at PARI. We worked most of the time in S-band, which is 2.10-2.30 GHz, and has a focused beam-width of about 18 arc-minutes. This is the easiest to use of our bands. It was a good place to start taking data, and most of our points were taken using this bandwidth. The other available bandwidth is called X-band, which is 8.15-8.35 GHz, and has a beam width of approximately five arc-minutes. Needless to say, this is the more accurate but harder to use of the two. No data had ever been taken in X-band until we were able to make observations about halfway through our summer. This was an exciting accomplishment because it had never been done before with the DIRV receiver, and because it showed that though out of focus, our instruments were able to detect a source at X-band.

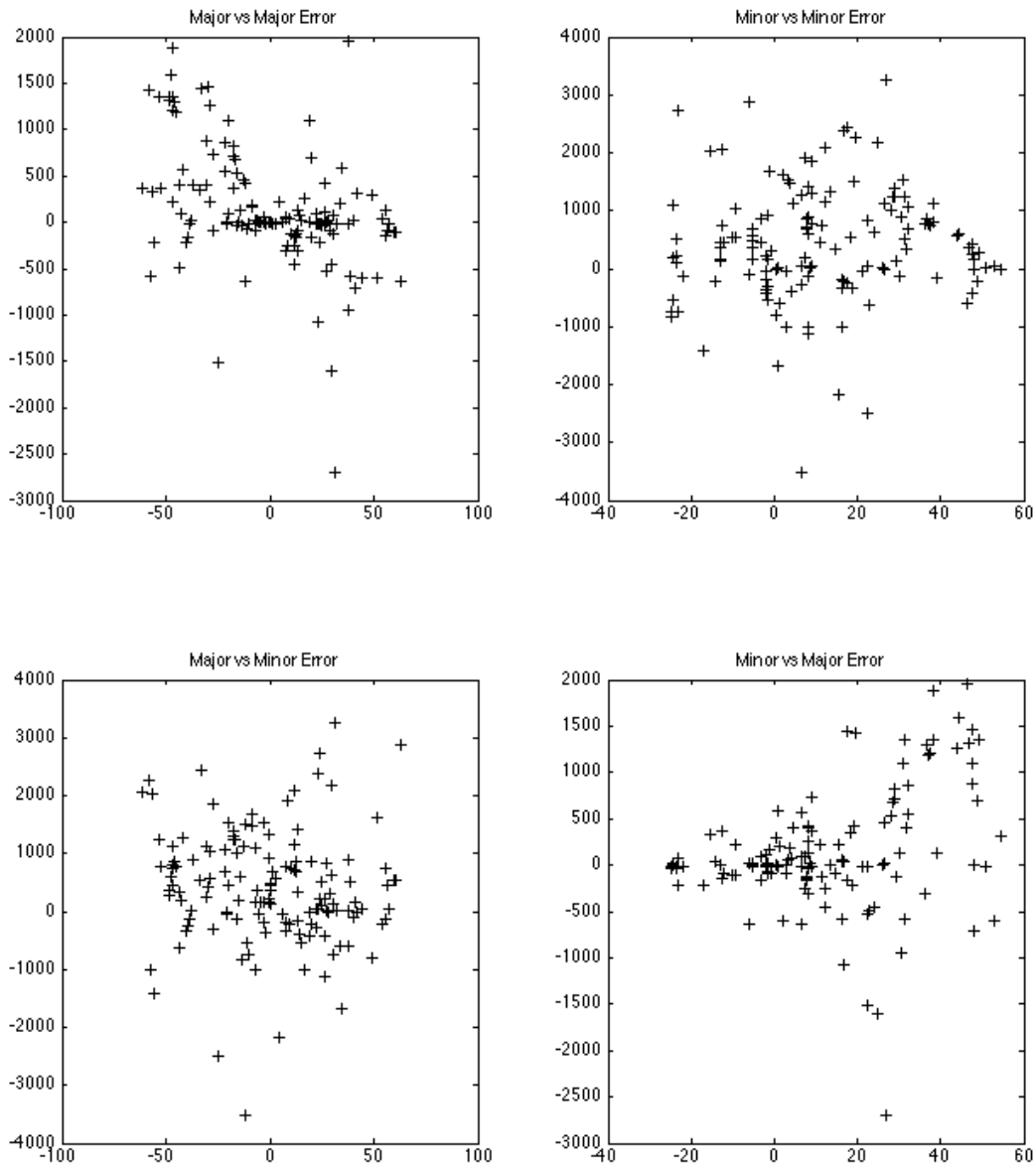

Figure 8: Graphs from pointing data from 26E

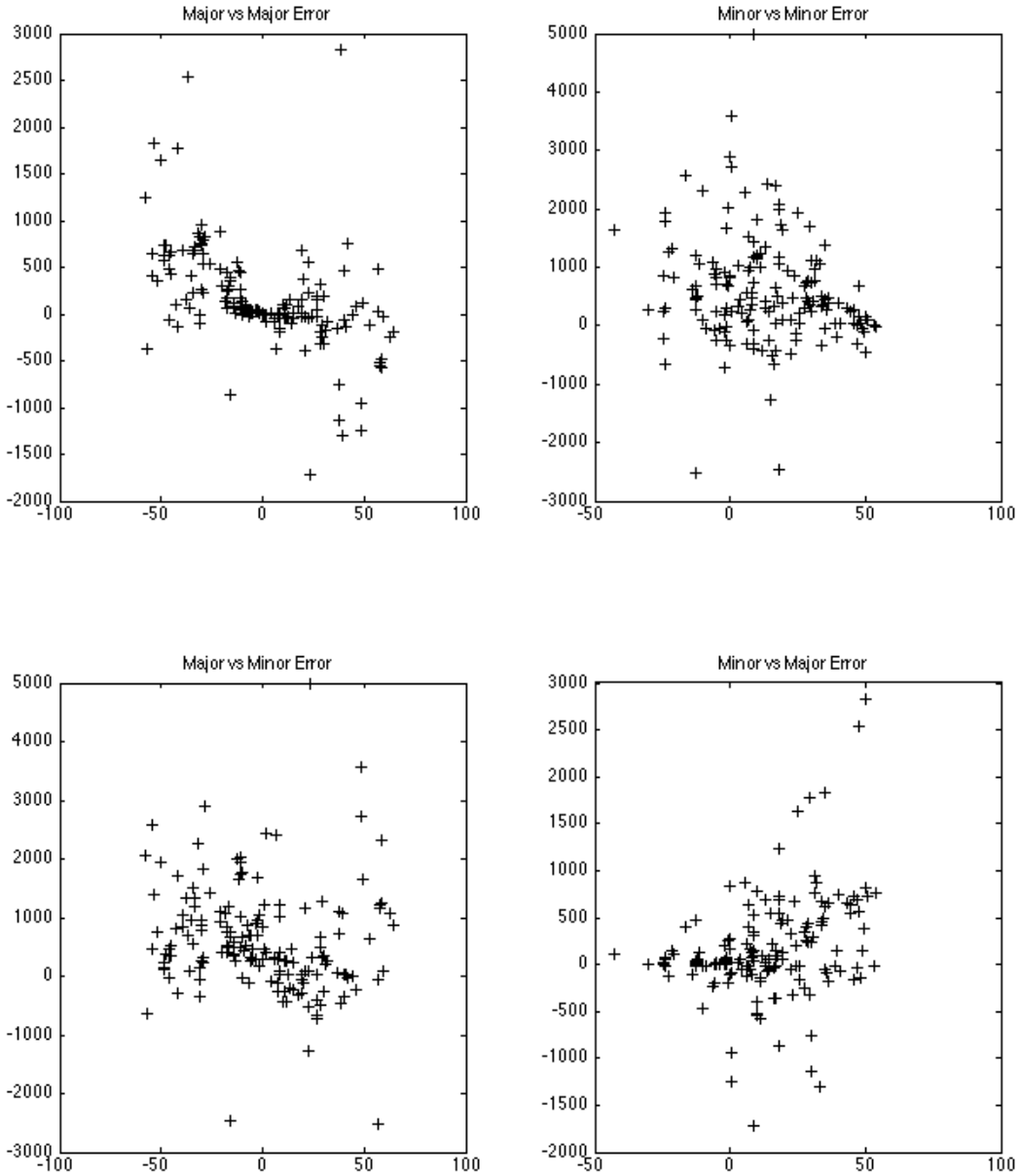

Figure 9: Graphs from pointing data from 26W

We did constantly face problems from radio frequency interference (RFI), which would interrupt our signal and make finding points impossible. This was much more common on 26E than 26W, and was consistent throughout the summer in both S and X-bands. We tried several modifications to hope to resolve the problem, including switching in different frequency band

pass filters, changing output channels, and putting in high pass filters, but these at best reduced the problem. As time went on, we noticed that the RFI we had been observing was due to DC drift from within the Wideband Detector – an issue that kept us from peaking up on fainter radio sources. By the end of summer, the UNC-A group resolved this issue by creating a program that would take faster total power samples from the IBOB autocorrelator, and create a raster scan of the power level in an area surrounding a target source (allowing for a better fit position for the pointing model). We plan to use this program through the fall of 2012 to refine our position data and refine the pointing model for both telescopes.

III. Conclusion

A. Results

By the end of the summer, we were able to show that PARI has the capability to operate an interferometer. We were able to find the first fringes in interferometer readings, and we know that with further work, we will be able to increase the sensitivity of the interferometer to a useful level. We diagnosed and created a temporary fix to the tracking problem in the antennae, and they are now able to stay on a source for an extended period of time. We also discovered that the antennae were out of focus. We arranged the correlator rack into an improved and more functional position.

We confirmed that the pointing model in the antennae was incorrect, and we accrued massive amounts of data points in order to fix this problem. We were able to conclude that there was a significant error, enough to require a proper model to be installed. Also, we have been able to make beneficial steps toward a new model with the points and graphs that we have accumulated.

B. Continuing Research:

In the future, the interferometer must be adjusted to be made more precise. Having a proper pointing model and focused antennae will definitely help in this effort. We would like to be able to observe fringes on smaller and more distant sources than we are capable of now. Also, finding and correcting the tracking problem in the antennae would be very helpful for future work, instead of having to rely on a program to track. It would be interesting to see what could be done with the accumulated pointing data, and hopefully this will be helpful in pointing models in the future. Another helpful way to further the interferometer box would be removing all the interference by either filtering it out or updating our instruments so they are more accurate.

IV. Acknowledgements

R. Picardi and L. Smith acknowledge support from NSF grant AST-0908266. We thank the staff of the Pisgah Astronomical Research Institute (PARI) for their hospitality and support during our visit. We also thank the mentors of the DIRV program, Dr. Brian Dennison, Dr. Charles Bennett, Dr. Joe Daugherty, Dr. Michael Castelaz and Dr. David Moffett, for their invaluable help. PARI is a not-for-profit foundation dedicated to providing hands-on education and research opportunities for a broad cross-section of users in STEM disciplines.

PARSEC SUMMER INTERN PROJECT REPORT
JOSEPH PETERS
UNC-ASHEVILLE
2012 PARSEC INTERN

Executive Summary

This report details the work I did as one of the 2012 Pisgah Astronomical Research and Science Education Center (PARSEC) summer interns at the Pisgah Astronomical Research Institute (PARI). The majority of the internship was spent working on the Dedicated Interferometer for Rapid Variability (DIRV). Details of the DIRV project as well as my contribution to it are outlined below.

DIRV

The DIRV project is a joint venture between PARI, PARSEC, and the Departments of Physics at UNC Asheville, UNC Chapel Hill, and Furman University. The project makes use of the two 26 meter radio telescopes on the PARI site which is located near Rosman, North Carolina. The DIRV team has spent approximately five years turning these two radio telescopes into an interferometer with a baseline of about 400 meters.

The purpose of DIRV is to study the intraday variability (IDV) and extreme scattering events (ESEs) of extra-galactic sources in order to study structures and turbulence in the ionized interstellar medium (ISM). By studying these rare phenomena, researchers can develop a better understanding of the structure of our galaxy. Since ESEs only occur approximately once per 50 years per source, it is necessary to continuously monitor a large number of extra-galactic sources to find them. Such observations could not be carried out thoroughly in observatories where time is split between different research projects, thus it was necessary to develop a dedicated system for these observations. It was developed as an interferometer since the extragalactic sources being monitored are typically on the order of 1 Jansky in power. These weak sources are normally only a few tenths of a percent of the total system power and therefore far too weak to detect conclusively with a single telescope. By using a simple interferometer, the source signal received by each telescope can be correlated and essentially picked out of the extraneous sources. A complete description of the DIRV research goals and background can be found in "The dedicated interferometer for rapid variability" paper published in *Astronomical and Astrophysical Transactions* Vol. 26 No. 6, December 2007, 557-565.

The DIRV feedboxes have been successfully installed in the 26 meter telescopes and the interferometer has been set up. The primary work of the DIRV team this summer, including myself, was to fine tune the interferometer and telescope parameters in order to prepare for data gathering.

Tracking

The 26 meter radio telescopes at PARI were originally designed by NASA to communicate with manmade satellites. The telescopes' motor systems were converted to radio astronomical use by the engineering firm DFM Engineering. DFM set up the telescopes to be able to track a radio source as it moves across the sky due to the Earth's rotation. It was found by the DIRV team that the tracking mechanism was not working correctly for either telescope. One of my first tasks was to record coordinate data as the telescopes tracked across the sky and attempt to identify patterns in the tracking error. In order to automate the data taking process, I wrote a program using LabVIEW which would send the telescope to a set of coordinates and

continuously record the actual coordinates while tracking was enabled. This data was then transferred to an Excel spreadsheet which plotted the telescope motion in the coordinate planes as well as a function of time. Figure 1 shows an example of these graphs for the RA/DEC coordinate system. There was no obvious, repeatable pattern to the tracking offset on either telescope.

There were several attempts to fix the tracking errors. Dr. Charles Bennett, a professor from the UNC Asheville physics department, reasoned there might be errors in the motor step calculations. The motor step size is one of the parameters which is adjustable in the DFM motor software. I re-worked the motor step calculations and found that the DFM calculations were in fact wrong. Figure 2 shows the gear ratio and step size as calculated by me and also the DFM values originally in the computer. The new motor values were input into the DFM computer, however, no obvious improvements were observed in the tracking offset. Another possibility put forward by Lamar Owen, PARI's Director of Information Technology, was that the tracking error may resolve itself once the telescopes' pointing models were updated. In the meantime, it was decided by Dr. Bennett that a LabVIEW program could be used which would automatically redirect the telescopes to the correct coordinates in a set time interval in order to cancel out the error in automatic tracking. This program was developed by Dr. Bennett, Jered Leisey, and myself and incorporated into the main control program for the 26 meter telescopes.

LabVIEW Control Program

The primary task set to me this summer was to update and improve upon the control program I wrote during my internship at PARI in the summer of 2009. This control program is written in LabVIEW and communicates with the DIRV and DFM computers through transmission control protocol (TCP). The 26 meter control program is very complex with several operating modes and pointing options.

The program is set up so a user can choose from three different telescope modes: East, West, and Sync. If East is selected the program only communicates with the 26 East telescope and vice versa for West. If Sync is selected then the program communicates with both 26 East and 26 West. The program only shows status and coordinate information for the selected telescope and only moves the selected telescope when any motion command is sent. If a telescope is selected but the program is unable to communicate with one or more of the telescopes then a pop-up window gives the user the option to enter DFM test mode, change telescope mode, or stop the program.

DFM test mode simulates the DFM computers without actually communicating with them. This is only useful for testing the DIRV functionality or the program itself and should not be used during normal telescope operation. The DFM test mode simulates normal telescope operation as closely as possible but does not simulate possible errors in the DFM computers or telescope mechanics. This mode uses two Excel spreadsheets named DFM Simulator East and DFM Simulator West located in the C:\LabView_8_6\Control_Data_Files directory. While DFM test mode is operating, the control program stores telescope status and coordinate information in these spreadsheets and calls it back as needed. This mode can be activated from the pop-up window when a communication error is detected or in the Program Diagnostics tab of the control program's front panel.

There is a DIRV test mode as well. Similar to the DFM test mode, this mode allows a user to simulate the DIRV computer's normal operating mode in order to test the program and again should not be used during normal operation. If a DIRV computer is not communicating with the control program then a pop-up window gives the user the option to either enable the

DIRV test mode, enable communication and click OK, or stop the program. The DIRV test mode may also be enabled in the Program Diagnostics tab of the control program's front panel next to the button for the DFM test mode.

In addition to selecting the telescope mode the user can also choose from five different operating modes. Three of these are single target modes where the user inputs target coordinates and the telescope moves to those coordinates when the Go button is pressed. The three coordinate types are RA/DEC, X/Y, or Object List where RA/DEC is celestial coordinate input, X/Y is the angle of the telescope from zenith, and the Object List is a list of radio source names the user can select from. In X/Y mode there is also an option to go to zenith, this will send the telescope to X=0 and Y=0 when Go is pressed. The other two modes available are From File and Pointing Model. The From File mode is most likely to be used during normal operation. This mode calls an Excel spreadsheet pre-created for this purpose. The Excel file is an observation list of radio sources for the telescopes to point to and take data. When this mode is selected the telescope mode is automatically set to Sync since the interferometer data taken is only meaningful if the telescopes are both pointed at the same source. For each object in the list the program waits until the time when the object is within range and then moves both telescopes to the correct coordinates. When both telescopes are on the source, a command is sent to the DIRV computers to take data. When the DIRV's are finished taking data it is stored on the DIRV computers and the control program moves to the next source in the list.

The Pointing Model mode automates the process of creating a PAT file required to update the telescope pointing models. More on the pointing model process will be covered in a later section. In this mode, the user has the option to either use an observation list or move to a single target. When the user presses "Go", the program runs through the observation list until it finds a target which is in range. The program then creates a set of raster coordinates which will sweep a user defined section of the sky. The program moves the telescope(s) to the first set of raster coordinates. When the telescope is on target a command is sent to the DIRV computers to take a total power reading. After the DIRV is finished taking data, the total power value is returned to the control program. This process is repeated for each coordinate in the raster. If a 5x5 raster is selected then the program will move to 25 different coordinates and take power readings. Once the raster is complete a black and white image of the object is created from the total power measurements (Figure 5). An Excel spreadsheet is also created for later analysis and a PAT file is updated with the object's catalog coordinates, maximum power coordinates and hour angle. There is also an option called Interferometer Model. If this option is selected then once both telescopes have completed their raster and determined the point of maximum power, i.e. on source, then both telescopes are moved to their points of maximum power. When they are on this source a command is sent to the DIRV computers to correlate the signal from both telescopes. Once all data is taken for the radio source the program moves to the next object in the pointing model observation file.

In all the operating modes listed above there are several functionalities in the program worth mentioning. The automatic tracking fix has already been mentioned above. In the control program the user has the option to turn tracking on or off and change the delay between tracking fixes. The Track Delay variable can be changed in the Local Variables tab and is set in milliseconds. There is also an Offset Plots tab on the front control panel. This tab has a plot for 26 East and 26 West which shows the offset between target coordinates and actual coordinates for both telescopes as time passes. These plots also have dashed white lines which indicate the region in which the telescope is considered in range. This value is defaulted to 20 arcseconds but

can be modified in the Local Variables tab of the control program's front panel. These plots allow a user to ensure the telescopes are staying on target and they can "see" the general motion of the telescopes. An observation log is also created each time the program is run. This log is stored in a .txt file which is continuously updated during program operation. These logs are stored in the C:\LabView_8_6\Control_Data_Files\Observation_Logs directory. The thirty most recent entries in the log are also displayed in a window on the front panel of the control program. Two other files are created by the program as well. One of these files is the raster data created in Pointing Model mode and was mentioned earlier, this file is stored in the C:\LabView_8_6\Control_Data_Files\Coordinate_Checking directory. The other file is tracking data. This data is stored continuously in a file created each time the program is run. This data continuously tracks the movement of the telescope and can be found in the C:\LabView_8_6\Control_Data_Files\Tracking_Data directory.

There is an additional functionality planned but not yet implemented which would continuously check for digital encoder errors. Each telescope has two digital encoders, one on the x-axis of rotation and another on the y-axis of rotation. These encoders are how the DFM computers can tell where the telescopes are pointing. It is important for each of the encoders to be functioning correctly at all times, otherwise the telescope motors would keep moving the telescope past the target until the hardware limits are reached. The difficulty in implementing the encoder checks is due to the fact that the DFM computers only return coordinates to the control program in RA/DEC, not X/Y. This means that we can't detect directly whether an axis value is not changing when it should be. Several LabVIEW codes have been written to detect encoder errors but none have yet been successfully tested. This functionality will be completed before the telescopes are ready for normal operation.

There are many other functionalities in the control program not included in this report for brevity sake. I intend to create a complete user manual once the program is completed which will be a comprehensive guide to the control program's functionality and use.

Pointing Model

One of the most important steps to be completed before the telescopes can be used for observations is to develop an accurate pointing model. A pointing model is how a telescope is set up so that it can be pointed towards the correct astronomical coordinates. DFM included a pointing model program in the computer software designed for the 26 meter radio telescopes. A user can use the DFM computer to point towards the catalog coordinates of a radio source and move around in the sky with the hand paddle while watching the power readout on an oscilloscope. The sources should be either along the line of x=0 or y=0. When peaked up on a source they can store the data point from the DFM software. This program stores all such coordinates into a PAT file with the original RA coordinate, original DEC, actual RA, actual DEC, and the Hour Angle at which the data point was taken. The LabVIEW control program I developed automates this program and creates a PAT file with the same format. The PAT file may then be used in a separate DFM program to adjust the telescope's pointing model.

The pointing model set up by DFM has eleven adjustable parameters which need to be fine-tuned in order to make the pointing model accurate. These parameters are: major scale factor, minor scale factor, elevation misalignment, azimuth misalignment, optical collimation, non-perpendicularity of major and minor axis, tube flexure, major encoder eccentricity, major encoder phase angle, minor encoder eccentricity, and minor encoder phase angle. The DFM software includes a program which can load a PAT file of coordinates in order to calculate the overall error of the pointing model. A user then manually adjusts the eleven parameter values in

order to reduce the error as much as possible. Once the optimal values are determined, these values are then updated in the DFM control computers. This process is repeated until the pointing model error is within acceptable ranges. The pointing models for the 26 meter radio telescopes are still being developed but should be finished in September 2012.

Additional Projects

In addition to the tracking, pointing model, and control program work there were several smaller projects I worked on this summer. In order to help develop the interferometer model I worked with other PARI interns to determine the latitude, longitude, and elevation of the base of the dish for each telescope. In order to accomplish this we took handheld GPS units up to the dish and recorded the values. Figure 3 shows the values we recorded for each telescope. I also created a LabVIEW program which will extract and analyze the raster data created by the control program during pointing model runs. This program extracts the maximum power coordinates and can take the average value from multiple runs and creates various plots to help analyze the pointing model accuracy. Figure 5 shows an example of the raster scan image and maximum power data produced from one of the data sets for Cas A. It was also necessary to create an observation list for the pointing model observations. This observation list needed sources which would cross the sky along either the x=0 or y=0 lines. These sources needed to be spread out across the sky in such a way that the times they crossed the zero lines were spaced far enough apart to allow time for the telescope to complete the raster and take the data. It was also necessary for the sources to be powerful enough to be picked up in the total power readout. Figure 4 shows a plot of the source power and viewing time of the objects in the observation list. These are some examples of the extra duties I performed during my summer internship with the DIRV team.

Conclusion

The summer internship working on the DIRV project at PARI has been challenging and rewarding. It was an excellent opportunity to improve my skills in astronomy, LabVIEW programming, Excel data processing, and coordinate conversions. I would like to thanks Dr. Brian Dennison, Dr. Charles Bennett, and the PARI staff for their support and expertise.

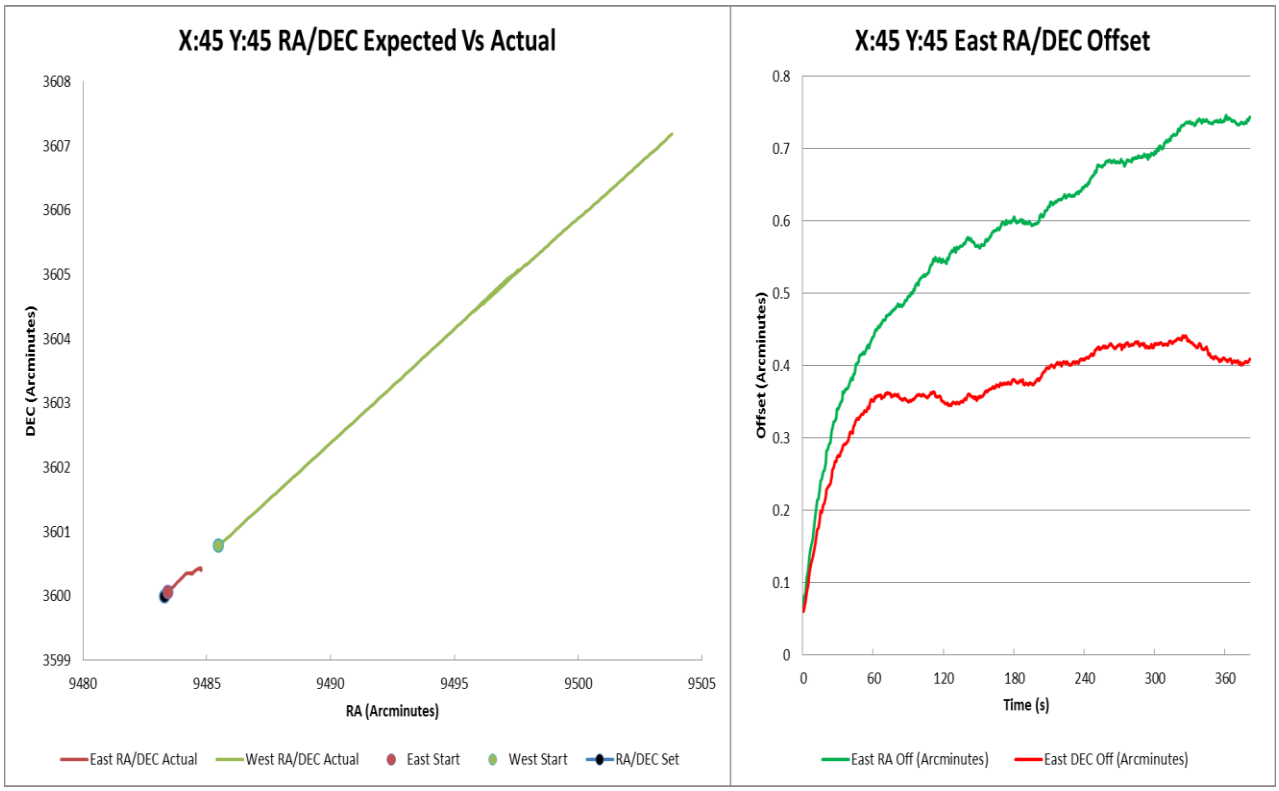

Figure 1: Tracking error plots

26 East						
Major X-Axis						
Timing Belt	**Gearbox**	**Bull Gear**	**Total Ratio**	**Steps/Rev**	**Arcseconds/Rev**	**Step Size: Arcseconds/Step**
3.21	37.112	81.81	**9745.986031**	8192	1296000	**0.01623264434132590**
		Current:	**9759.97**		**Current:**	**0.01620937000000000**
Minor Y-Axis						
Timing Belt	**Gearbox**	**Bull Gear**	**Total Ratio**	**Steps/Rev**	**Arcseconds/Rev**	**Step Size: Arcseconds/Step**
3	66.852	75	**15041.7**	8192	1296000	**0.01051763597199780**
		Current:	**15041.74**		**Current:**	**0.01051857000000000**

26 West						
Major X-Axis						
Timing Belt	**Gearbox**	**Bull Gear**	**Total Ratio**	**Steps/Rev**	**Arcseconds/Rev**	**Step Size: Arcseconds/Step**
3	43.81	72	**9462.96**	8192	1296000	**0.01671814368865560**
Minor Y-Axis						
Timing Belt	**Gearbox**	**Bull Gear**	**Total Ratio**	**Steps/Rev**	**Arcseconds/Rev**	**Step Size: Arcseconds/Step**
1	74.719	65.48	**4892.60012**	8192	1296000	**0.03233518397575480**
		Current:	**4892.9**			**0.03233300000000000**

Figure 2: Motor step calculations

26 East	N (deg)	W (deg)	Elevation (m)	26 West	N (deg)	W (deg)	Elevation (m)
Nuvi	35.20011667	82.87196667	885	Nuvi 1	35.19893333	82.87546667	897
				Nuvi 2	35.19891667	82.87555	897
				Nuvi 3	35.19891667	82.87556667	897
				Nuvi 4	35.19893333	82.87546667	897
CX	35.20015	82.87191	900	CX 1	35.19894	82.87553	890
				CX 2	35.19893	82.87556	890
				CX 3	35.19892	82.87557	890
				CX 4	35.19891	82.87557	890
Garmin	35.20083333	82.91888889	894	Garmin	35.19888889	82.87552778	883
Average:	**35.20036667**	**82.88758852**	**892.8912**	**Average:**	**35.19892099**	**82.8755342**	**892.3339556**

Figure 3: Telescope latitude, longitude, and elevation measurements

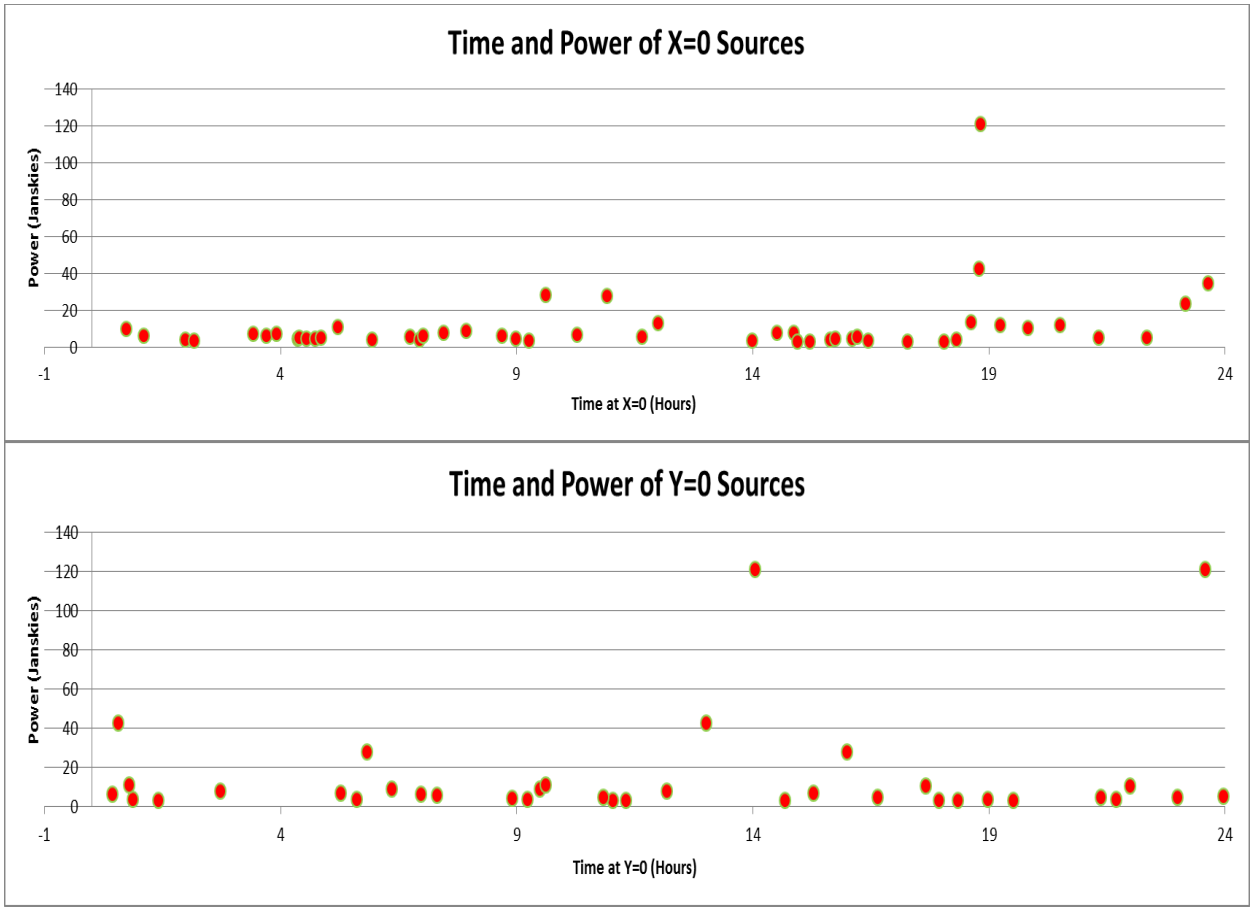

Figure 4: Pointing model observation list time and power plots

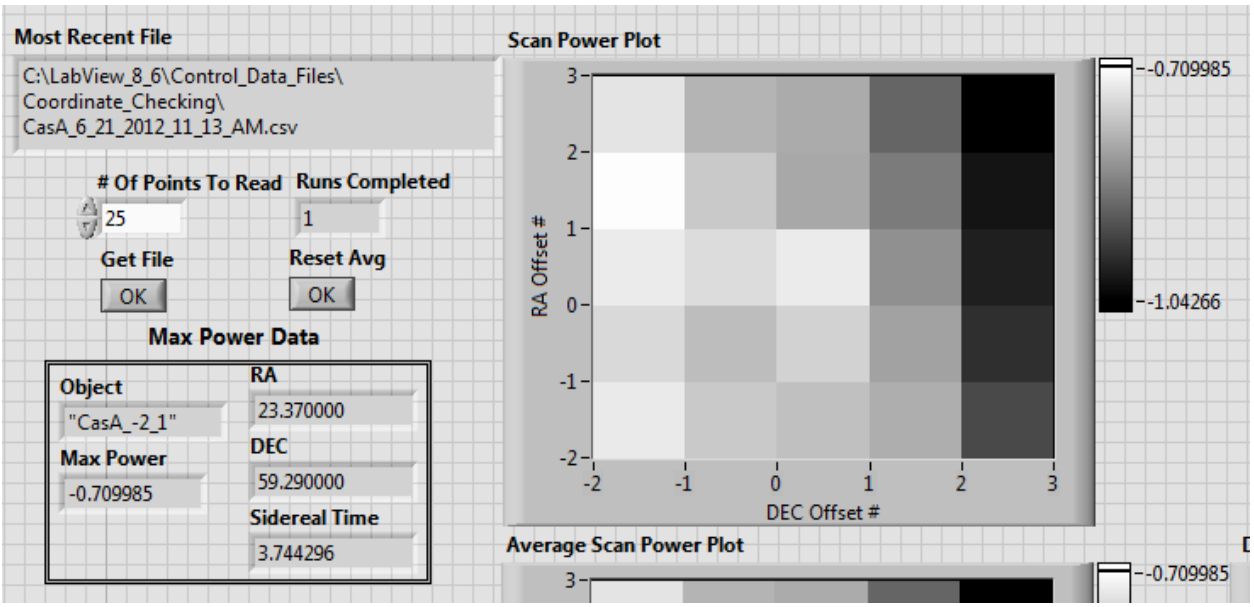

Figure 5: Raster scan plot and maximum power data

Western Carolina University

Kimmel School of Engineering
Senior Capstone Project 2011-2012

Students
Veronica Flamenco, Joshua White, and Josh Williams

Faculty Mentor: Dr. Paul Yanik

Project Title: The PARI Star Spectra Plate Scanner

Left-Right: Joshua Williams, Dr. Paul Yanik, Dr. Michael Castelaz, Thurburn Barker, Veronica F;amenco, Joshua White

Executive Summary of Project

Description:

We are building a computerized control system for the spectra scanner (mini GAMMA) that can run the motors and take the image read by the scanner and store them into a digitized format. We will be researching and investigating all the functions of the GAMMA II in order to incorporate it into the mini GAMMA. We will be using the mini GAMMA instead of the GAMMA II for purposes of mobility and proper testing.

Problem:

Our customer mentors have over 100,000 photographical plates in the Pisgah Astronomical Research Institute and we need to design a way for all these images to be scanned with the GAMMA II machine in order to put them into the Astronomical Photographic Data Archive (APDA).

Solution:

Research: We will begin by researching the GAMMA machines datasheets/ manuals, patents, as well as research the specifications.

Grid correlation layout: We will have an x,y grid system and have it relate to the motor controlled positioning.

Digitization: We will have the computer control the laser at the previous specifications and convert the scanned images into a specified file format.

What will be produced:

We will produce a more precise and faster scanning process by using a motorized x,y positioning system for the GAMMA scanner; which will scan the images into the APDA.

Testing:

We will determine the x and y motor functions on the mini GAMMA as well as do any debugging needed in the computer aspect of the system.

We will test the compatibility of the motor devices as well as the software of the machine.

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1.1 Statement of Problem

Currently, the Pisgah Astronomical Research Institute (PARI) holds an extensive archive of star image and spectra plates which need to be digitized for research and dissemination. The present scanning method utilizes obsolete hardware and software which offer poor performance in the scanning process as well as maintenance concerns.

Our team will update the spectra scanner (mini GAMMA) for PARI to provide an up to date and manageable system to generate scanned images for their Astronomical Photographic Data Archive (APDA). The heart of this scanner will be a computer controlled micron-level positioning system. The current harware and software in use dates to the 1980's and requires update to current technology.

PARI desires a system that allows this information to be distributed for education, research, and presentation. Because the library of plates is massive (exceeding 120,000), an improved means of image extraction is key to their effective use of the data toward this mission. This system would facilitate extensive and broad access to astronomical data by astronomers and researchers throughout the world via the internet while reducing their current travel expenses. Such access would also benefit the customer through a heightened profile as a center of astronomical research and education.

1.2 Survey of Competing Products

No other prior approaches, that we are aware of, have been made to improve the GAMMA scanner. We will be working very closely with our mentor, Dr.Castelaz, so that our final solution will be exactly what he and PARI have envisioned for their system. The product that comes out of this process will be the first of its kind and hopefully inspire further solutions and future designs. The product that is produced will be for PARI and will be used as a foundation for research and education. There are a small number of outlying GAMMAs located around the world that are likewise used in astronomical research and study. The GAMMA systems are not intentionally constructed for competition for it is the intent of the curators of the machines to draw in the interest of astronomical personnel and general populace.

1.3 Existing Products

The Guide Star Automatic Measuring Machine (GAMMA) is a laser scanner that scans the photographical plates to digitize astronomical images. Photographical plates date to the early 1800s. They have been used to find celestial bodies in space. The GAMMA machines were developed in the 1980s. They were used by astronomers to study the information read from the plates in order to measure the positions of the stars and other objects in space as well as to study their composition. Three GAMMA machines where given to the Pisgah Astronomical Research Institute (PARI) in early 2000s to further their research in astronomy and their understanding of the behavior of celestial bodies.

The GAMMA II is a room size device which consists of a scanner mounted on a heavy marble base to limit vibration. The head of the device which holds the laser scanner is stationary whereas the lower platform moves in two directions. A VAX computer serves processing and storage point for the GAMMA II. It runs a VMS operating system. It can scan various plate sizes. There are only a few other research facilities in the world that have other GAMMA machines which do similar processes.

The mini GAMMA is a smaller version of the GAMMA II. However, unlike the GAMMA II, the mini GAMMA plate platform moves in both the x and y direction. It has a microscope in which one can see the images of the plates as the table moves. Out of the three GAMMA machines in PARI we will only be using the GAMMA II and the mini GAMMA.

The strengths of these machines currently are that they can scan images of the photographical plates and we can learn the positioning of the objects in space relative to other stars, galaxies, and objects in space. One of the features that make the GAMMA machines exceptional is the precise scanning capabilities that allow for resolution down to one micron. The main weakness of the machines is that they currently do not interface with the newer technology. Another weakness is a lack of image correlation and a positioning system with a grid layout to map the specific stars will be used to correct this problem. Due to its rigid design the GAMMA II is stationary and therefore inconvenient for mass-mediating the information stored on the plates.

1.4 Scope of Work

Our team will design, build, test, and install a new control system for the spectra plate scanner (mini GAMMA) in the PARI/GAMMA II Project which will incorporate an up to date precision motor control system. We will design a process that will allow a computer to control the scanner so that no manual operation will be required, although a means of manual control will be included. We will use the mini GAMMA as a prototype for further development of GAMMA II. We will test the updated mini GAMMA on site at PARI and/or on campus. Our main focus will be motorizing the x-y table, as opposed to the requirements of the camera and the outcome it will produce.

The control system will allow planar *(x,y)* movement which will allow micron resolution and precision accuracy for the *x,y* table. Travel in the x and y directions will be 29.85 cm and 10.8 cm respectively. The overall scanning speed per one plate will be approximately 5 minutes.

The system will run on a Linux based platform. Scan output data will be rendered in ASCII text. The newly scanned images will be uploaded to and accessible from the Astronomical Photographic Data Archive (APDA) at PARI. The system will be fully transferrable to the GAMMA II with installation and testing on the GAMMA II (time permitting). At completion we will delver the updated scanner system along with software tools to permit scripting of essential scan tasks.

1.5 Team Members and Roles

Expectations:

- We are committed to being open with ideas and opinions.
- We are willing to put in however many hours it takes to complete the project on time and to the best of our abilities.
- We will do the research to further our understanding of the project.
- We will do our individual share of the work.
- We will assist each other with any barriers we come across.
- We will not leave anyone out of the project.
- We will keep mentors up to date on the projects progress through weekly meetings.

Roles:

- Project Manager: Josh Williams
- Machine Designer: Josh Williams
- Budget Coordinator: Josh Williams
- Scheduler/Timekeeper: Veronica Flamenco
- Paperwork/Organizer: Veronica Flamenco
- Analyst: Veronica Flamenco
- Interface Designer: Josh White
- Software Designer: Josh White
- Faculty Mentor: Prof. Yanik
- Customer Mentor: Dr. Castelaz/ Dr. Clavier

2.2 Conceptual Design Plan

Initial research will be performed to detail the operation of the spectra scanner (mini GAMMA) currently in use. We will also research the differences between the mini GAMMA and the GAMMA II as well as learn about the Linux software. The positioning system of the mini GAMMA will be investigated in order to create a system which can accurately store the information produced by the scanner in a digitized format.

Several different models will be used in the construction of the spectra scanner. The spectra scanner system will be divided into two main construction models: an *x,y* grid positioning system and a transfer system of the physical data into a digitized form. The mini GAMMA will be used as a prototype to lay the foundation for updating the GAMMA II. The mini GAMMA will be modified according to the specifications of the requirement matrix.

We will be testing the motor functionality of the mini GAMMA slide platform to develop an interface between the computer and the positioning motors. Testing of an automatic correction feature will be necessary to account for backlash in the movement of the motors. Different programming languages will be analyzed to determine the one most applicable to our design concept.

2.2.1

We began by researching the functions of other GAMMA machines in different locations around the US. We found that the one at Harvard was recently updated to similar specifications of the mini GAMMA. The main upgrades that they did to the one in Harvard was updating the x-y table with new air bearings and linear motors, a CCD chip, new focal lens, LED light system, computer and storage system. The air bearings allow for smoother precise movements along the x and y directions, while the servo stepper motors had a smaller step size which showed an increase in the movement accuracy of the table. The CCD allows for faster digitization of the images that are being scanned and sets them to an x-y grid. The focal lens distortion is the largest source of error in the system so a good lens provides more exact measurements of the image. The light system was updated to numerous LED's placed specifically over a 1 sq. in. area and unlike the old system the lighting now can be controlled remotely through the computer system. The computer and storage system was improved by updating it to terabytes of memory and can transfer data up to 528 Mb/s and the software was updated to run on both XP and LINUX.

We then began researching the specifications of the mini GAMMA. Most of our research for the mini GAMMA came by means of working hands on with the machine and verifying how the system works mechanically and electronically. We started by removing plates both on the back and top of the machine. This allowed us to see that the top half of the machine was used only for manually viewing the plates (similar to a microscope). We also removed this section to allow room for a CCD camera/photodiode which will provide access to view the images electronically instead of manually. While removing the plates on the machine we found that the original light source was an incandescent light bulb that was made in the 80's, but it will be upgraded to an LED.

The x-y positioning is another subject that was of importance. The main aspects of the x-y positioning were the motors, mounting for the motors, and the remote control aspects of the positioning. When researching motors, we decided that stepper motors would work best for our application. This is true because they can turn in increments that are necessary in meeting the specifications of our distance of microns. We found three different motors that each corresponded with three different microcontrollers which will be needed for the computer control of the motors. In mounting for the motor in the x-direction, we are most likely going to replace the existing motor which is underneath the table or mount the new motor to the wheel bearings on the shaft. In the y-direction, we are considering mounting the motor to the manual gear on the x-y table. Depending on the whether we mount the x motor to the bottom of the table or not, will determine if we will need to mount a weight on the opposite side to keep it level. We will need a microcontroller to relay the information to the computer system which will allow for remote control movements of the x-y table.

The grid layout is used for a standardization of the origin for the plates during the scanning process. One layout we found is called a CCD pattern which is actually two separate grids but when combined make one, this pattern there is a constant y-grid on the x-y table, when a plate is placed on it to be scanned, the CCD chip views the area of the plate then lays an x-grid across that area, which produces an x-y grid only on the area where the plate is. This allows the positioning on the plates to become standardized because the bottom left hand corner of the plate is always set as the origin (0, 0).

Programming languages which fit best to our application were C and Java. Depending on the microcontroller that we choose to use, it will determine the language that we will use.

In researching the camera we found that PARI will be providing us with one they have. The camera they gave us is a CCD camera which might be used, depending on if the photodiode is a better choice. We found that the camera is picking up some images; although, it is not focused to the micron level. Later on, they will implement a newer camera or photodiode which will meet their specifications. We compared a stop and shoot method versus a continuous scanning method for scanning the images. We decided that a continuous scanning method would work best because a stop and shoot method would increase scanning time while a continuous scan decreased it to the time specified in the requirements.

While investigating encoders, we found three different ones that fit our specifications. The functionality of encoders consist of counting the rotations of the shaft in increments and sending that information as an analog or digital signal to give a read out of the information it has stored. The chosen encoder will be used as a feedback to assist in correcting any backlash in the design with the microcontroller.

2.2.2

The construction model that we did was a cardboard camera/photodiode mount prototype. The prototype that was constructed was the stable mount for the camera/photodiode. For this prototype we constructed the model to exact size and specifications for the mount.

Figure 1: Side View of Stable Mount

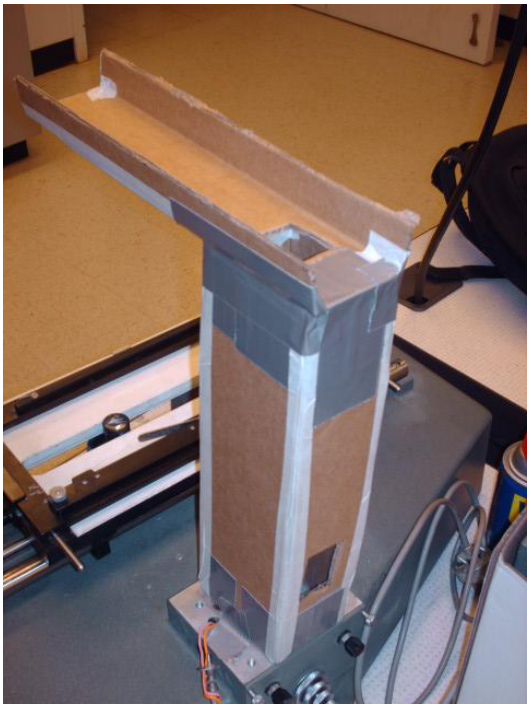


Figure 2: Back View of Stable Mount

We learned that the dimensions of the mount that we chose is accurate enough to start building/ordering our material. We also found that we can not make a hole into the camera to attach it so we need to come up with a way to fasten our camera/photodiode onto the actual mount.

2.2.3

While first exploring the machine, we plugged it in and turned it on, examined all the knobs and switches, to see what they controlled. We mainly were concerned with the speed of the motor because that was one of the requirements on our matrix. We found it was going 1 cm in 10 min. We needed it to go at least 20 times faster; in order for this to happen, a new screw shaft and motor will have to be ordered.

In researching the motors for the machine, we found that we would have to mount the motor, for the x-direction, either to the wheel bearing or where the old one is currently. In the y-direction, the motor would have to be mounted on the left side where the manual knob is.

PARI provided us with a camera for the mini GAMMA, and while trying to mount it on to the machine, we determined it would not fit with the arm that was on it. The function that the arm had was to manually look at the plates, like a microscope. So we removed it because we needed room to mount the camera and with it gone, we will rebuild an arm that will allow room for it.

The lighting system in the mini GAMMA currently was an incandescent light bulb that was 5V and 18W, from the 1980's. We are going to replace it with an LED; it will provide the same amount of lumens as the current light bulb.

2.2.4

In researching the concepts that were going to apply to updating the scanner, we found that we had different subcomponents of the machine that we could choose from, instead of having three different designs.

There are three different encoders that we found that would work with our design, the AccuCoder model 260, the AccuCoder model 25 t/h, and the AccuCoder series 85. They all do the same functions, therefore, have the same advantages. All three encoders are small in size and they fit onto the shaft on our machine. They also interface with the microcontrollers that we chose. The disadvantages of them are that they are all expensive, ranging from $260- $403.

We found three motors that met our specifications for our machine. The difference between all three is that the 23D102 is round and weighs the most, the TSM15-180-12-12V uses magnetism to control the increments and has the shortest shaft diameter and length, and the 23Y002S-LWB has the most leads and is more versatile in its adaptability in a circuit, due to its interchangeable clams. The disadvantages of using each would be that the 23D102 would be that it costs the most, the TSM15-180-12-12V might have a shaft diameter too small as well as a short length, and the 23Y002S-LWB would have too many leads.

All five microcontrollers that we chose were chosen because they are all capable of driving the motors that we chose and also interface with the programming language that we will use. The advantages of these three, the PIC-18c452, the PIC-16f684, and the DS-PIC-33fj64mc802 use MP lab (a C based programming debugger) and are very versatile and interface with the computer. The only disadvantage would be the power constraints of each of the motors. The

other two, the PIC32MX795F512L and the ATMEGA328P-PU use a Java based Arduino programming debugger. The advantages of these two are that they can run any motor. The disadvantages of these two are that they have a limit to the number of leads they can operate.

The three LEDs that we chose for our design are Cree MC-E, Docare A60, and Neco MR 16. The differences between these three are the brightness, the power requirements, and the price. The advantage of the Cree MC-E is that it puts out the most light and is the cheapest. The Docare A60 uses the most power out of these three so that would be a disadvantage. The Neco MR 16 uses the least amount of power but it is the most expensive.

The speed of the x-y table is supposed to be 50 um/s and in order to get it this fast we will need to consider which motor will be capable of reaching this speed. We also have to take into account the threaded rod. The pitch of the rod will increase the accuracy of the table because the smaller the pitch the more precise we will be in scanning. The pitch size relates to how far the motor has to turn the threaded rod which will control the accuracy because it is easier to turn a finer pitch two revolutions than it is to turn a more coarse pitch a small amount.

The programming language that we might use is C or Java. Depending on the microcontroller that we choose, it will determine the language that is needed.

For the camera/photodiode mount we generated two designs that will be only produced in CAD, and not physically produced. The two designs are a stable or a movable mount. The stable mount would be similar to the original design but it would be higher so that the camera can fit underneath. It will have a main arm that will come up from the base of the machine and on top of that arm there will be another piece extended off the top that will hold the camera/photodiode. The benefit of this design is that it will be stable and increase accuracy of the images, while the table is moving. Another advantage is that the materials that will be used will allow for the wiring to be run through and out the back, which will be out of the way. The disadvantage of this design is that if the camera is extremely large it might not be able to fit. The movable mount will be similar to desk lamps that move with multiple hinges. This will allow for more manual control of where you want to place the camera/photodiode when beginning scanning. The disadvantage of this design is that images might not be as focused because of the height adjustments and the vibrations while the scanning is occurring.

While considering the x-direction motor mount we came up with two different ways of mounting it. The concepts of mounting the motor were to mount it on the wheel bearing underneath the x-y table or to replace the existing motor which is located underneath the base of the machine, which attaches directly to the screw shaft. The benefit of mounting to the wheel bearing is the motor is more easily accessible. The disadvantage is that you would have complications with the wires being out in the open and could potentially get tangled up in moving parts. The benefit of replacing the existing motor is that the motor is out of the way and all the wiring will be underneath the table. The disadvantage is that the motor is not as accessible beneath the table.

While figuring out ways in mounting the motor for the y-direction, we found two ways that we could mount it. The first way would be attaching the motor to the left side where the manual control knob is and either attach the x-y table to the screw shaft attachment or attach a weight to

the right side of the x-y table to balance it. The benefit of attaching it to the screw shaft would be that you would not have to add extra weight to the x-y table to keep the table balanced. The disadvantage would be adding pressure on the screw shaft which would add friction which could slow down the speed of the scans. The benefit of attaching a weight to the right side would be not altering changes in the y-direction of the machine. The disadvantage would be if the weight did not exactly balance out the x-y table then it would throw off the scanning accuracy of the machine.

While working with the machine we found that there is a rod that controls the range of movement of the x-y table. We were considering in either taking it out or leaving it there, preserving the original design. The benefit of taking it out is that it will allow more range of movement. The disadvantage with taking it out would be it could possibly move off the rails. The benefit of leaving the rod in place would be to maintain the old design of how it was intended to work. The disadvantage is that the range of the movement would be minimized.

2.2.5

Encoder					
Criteria	**Weighting Factor**		AccuCoder Model 260	AccuCoder Model 25 t/h	AccuCoder Model 15TH
Price	0.3		0.737	0	1
Bore Size	0.1		1	0	1
Max Frequency	0.2		0	1	1
Angle Accuracy	0.4		1	0	0.922
		Total	**0.7211**	**0.2**	**0.9688**

Figure 1: Encoder Matrix

Motor					
Criteria	**Weighting Factor**		23D102	23Y002S-LWB	TSM15-180-12-12V
Price	0.3		0	0.446	1
Torque	0.2		0.986	1	0
Number of Leads	0.2		0.5	0	1
Step Angle Accuracy	0.3		1	1	0
		Total	**0.5972**	**0.6338**	**0.5**

Figure 2: Motor Matrix

Microcontroller							
Criteria	**Weighting Factor**		DS-PIC-33fj64mc802	PIC32MX795F512L	PIC-18c452	PIC-16f684	ATMEGA328P-PU
Price	0.3		0.996	0	0.939	1	0.815
Number of Pins	0.3		0.28	1	0.52	0	0.36
RAM Memory	0.4		0.124	1	0.003	0	0.014
		Total	**0.4324**	**0.7**	**0.4389**	**0.3**	**0.3581**

Figure 3: Micro-Controller Matrix

LED					
Criteria	**Weighting Factor**		Cree White XLAMP MCE LED WT 280 LM	Cree White XLAMP MCE LED WT 430 LM	Cree Multi Color XLAMP MCE 100 LM RGBW cool
Price	0.2		1	0	0.632
Lumens	0.4		1	0.625	0
Spectra Range	0.4		0	1	0.523
		Total	**0.6**	**0.65**	**0.3356**

Figure 4: LED Matrix

We have four different matrices which are for the encoder, motor, microcontroller, and the LED. Each of the four components has different set of criteria which will help in determining the best suited part for our project. During our selection process we also had to take into account the interaction and compatibility of all the parts to one another. The reason these four components had a decision matrix was because they all interact with each other and are the main components that we have to take into consideration in our project. As shown above in Figure 1-4, you can see the different weighing factors that were placed for each criterion in each of the four different components. The results for all four components are listed below:

Encoder: Accucoder Model 15TH
Motor: 23Y002S-LWB
Microcontroller: PIC32MX795F512L
LED: Cree White XLAMP MCE LED WT 430 LM

2.2.6

The components that were selected for the final design are listed below:

Encoder: Accucoder Model 15TH
Motor: 23Y002S-LWB
Microcontroller: PIC32MX795F512L
LED: Cree White XLAMP MCE LED WT 430 LM

The mount for the camera/photodiode that will be used is the stable arm mount design.

The programming software that will be installed is Arduino and the programming language that we will use is Java/C because both can be used.

Instead of changing the screw shaft to achieve more accuracy we decided to alter the gears on the motor to achieve more precise movement of the x-y table.

The rod under the x-y table that controls the range of movement of the x-y table will be removed.

The mounting of the motor on the x-direction will be underneath the x-y table where it currently is on the old design.

The mounting of the motor on the y-direction will be mounting the motor where the manual knob currently is and we will add a weight on the opposite side to balance it.

Due to the setup that we chose, we will need motor controllers to help control the step and speed of the motor while interfacing with the microcontroller.

Formula we used to determine the speed of the scanning process of each plate:

- $$125{,}000\,pix\left(\frac{1\mu m}{1pix}\right)\left(\frac{1step}{5\mu m}\right)\left(\frac{1\sec(rpm)}{200steps}\right)\left(\frac{1\min}{60\sec}\right)=2.08\min$$

From this we decided that we will use a one-to-one gear ratio to move the *x*,*y* table the five micron precision that is needed.

2.2.7

Budget:

Components	**Quantity**	**Price**	**Total**
• Encoders	2	$219	$438
• Microcontrollers	1	$62.65	$62.65
• Motors	2	$63.74	$127.48
• LED	3	$16.59	$58.02
• Motor Controllers	2	$121	$242
Total:			$928.15

2.2.8

While researching all the components that we will need to order for our project, we will not have anything that will be taking more than six weeks to order.

2.3.1

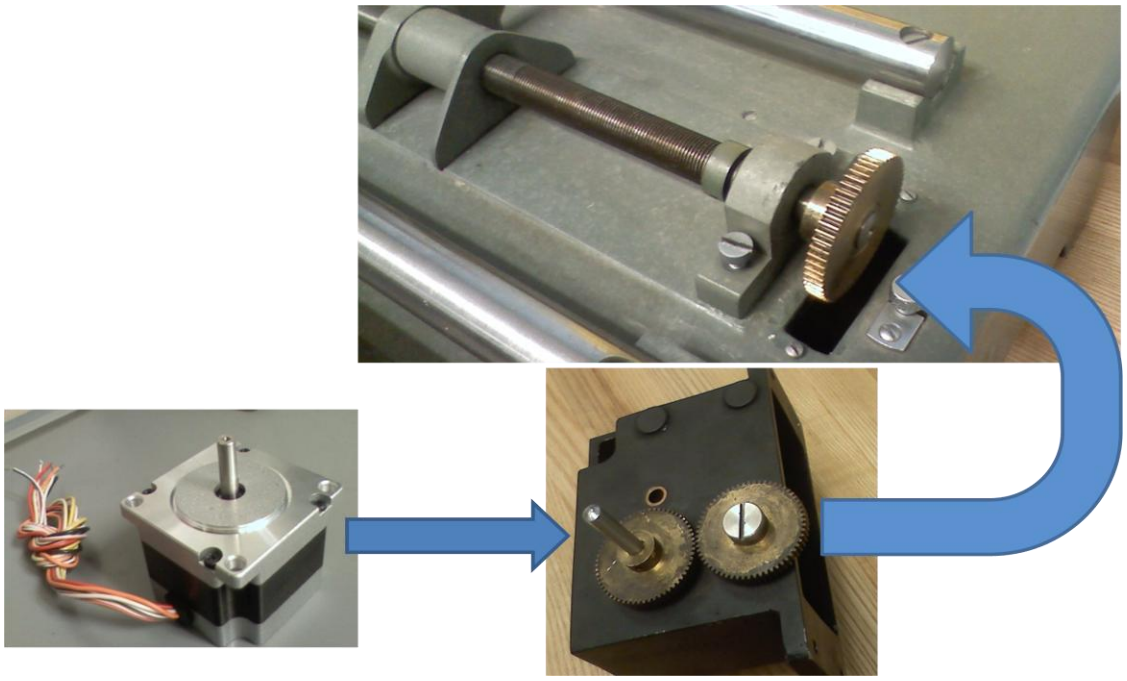


Figure 1: Placement of motor and Gear box

Figure 1 shows the mechanical aspect of our design. The motor will attach to the shaft of the gearbox, which we will be reusing from the old design. The gearbox is re-engineered to have the gear ratio that is now needed, which is 1:1. The gearbox will be mounted underneath the machine and the top gear will come up from the slit in the top of the machine, shown above. The

gear that will be coming up through the slit will pair with the third gear that is attached to the screw shaft, which propels the table for scanning.

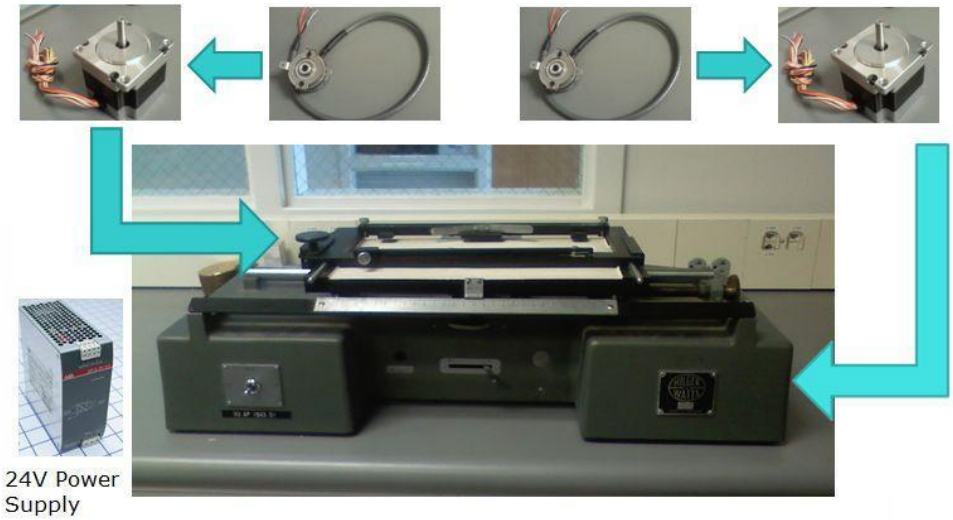


Figure 2: Placement of all subcomponents on top of the machine

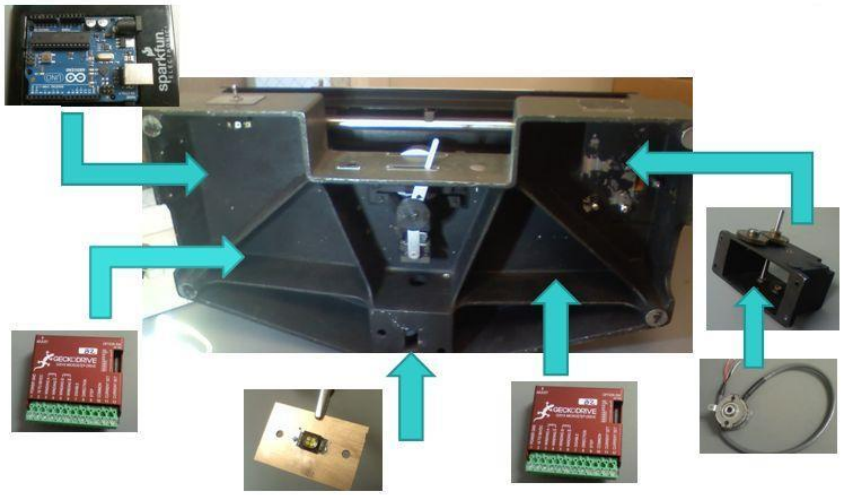
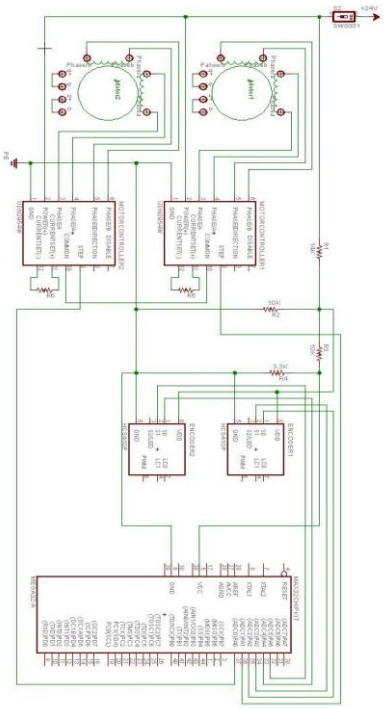


Figure 3: Placement of all subcomponents underneath machine

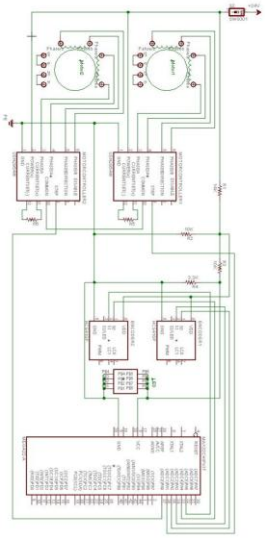
2.3.2.1



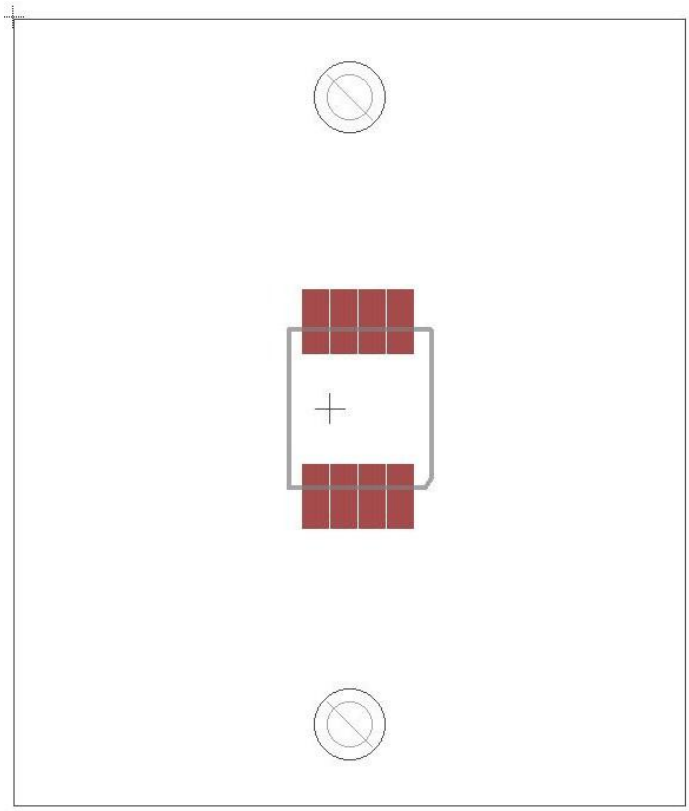
2.3.2.2

We tested the microcontroller and motor setup on the breadboard and found that at 7 volts the motor could turn one revolution in one second. The encoder was tested in a similar manner and between every 1 and 2 degrees rotation a signal was sent to the microcontroller. Based on our results we have concluded that our components are in working order and will meet the standards set by our customer mentors.

2.3.2.3



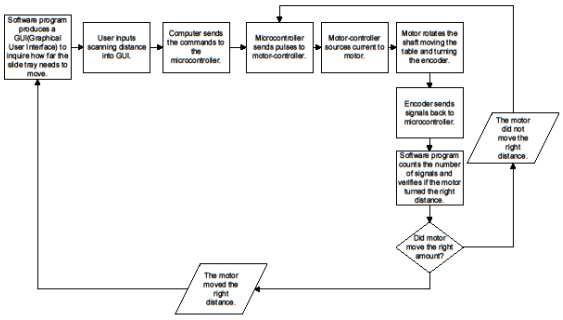
2.3.2.4



2.3.2.5

Our electrical design consists of two motor controllers and two encoders attached to the analog ports on a Max32 ChipKit microcontroller. On this, each motor is powered by a motor controller which also powers an LED. The main circuit is divided into two main sections: the microcontroller section and the LED section. The microcontroller section is further broken down into its input and output segments. On the output side we have the motor controllers which drive the motors and on the input end we have the feedback encoders. In assembly and process testing, our circuits will start with the motor controllers being attached to a 24 volt voltage supply through a switch. Two voltage step-down branches will be made in conjunction with the main voltage switch to make a 10 volt supply for the encoder and a 3.3 volt supply for the microcontroller and LED. Following the power hookups will be the attachment of the motors to the motor controllers. Resistors of varied values will be tested with the motor controllers to ensure that the current and voltage supplied by the motor controllers is sufficient to run the motors under load at the speed required. Afterwards the motor controllers and encoders will only need their signal transmission plugged into the ports on the microcontroller. Debugging of the encoders and motors will be more dependent on the software once their assimilations into the circuit are complete. The assembly process will end with the addition of the LED which will be set on a branch-off circuit with a separate switch for on/off control, making the final debugging process a simple matter of checking connections.

2.3.3.1



2.3.3.2

We will be using the Arduino programming software to operate the motor controllers and receive information from the encoder through the Max32 ChipKit microcontroller. The plan for software development is to use pre-constructed programs as guidelines for input and output pin configurations and command sequences. From there, we design the program's functionality in three different sections. The first will provide a prompt for the user to input a specific distance for motors to move. The second section of the program will send pulses to the motor controller at a specific time interval based on a formula that takes the input value provided by the user and coverts it into time duration. The third and final piece of the program will read the feedback pulses from the encoder and convert the signals into a numeric value that is displayed on the screen, letting the user know how far the motor has turned. After the motor has finished moving and the encoder value is displayed, the program will loop and prompt the user again for input.

2.3.5

The budget for fabrication phase will be the material needed to attach all components to the mini GAMMA.

Component	**Part Number**	**Quantity**	**Price**	**Total**
Bolts	Model 29034	20	$4.19 for 25	$4.19
Nuts	Model 31992	20	$4.24 for 50	$4.24
Brackets	Model 14937	6	$14.24 for 10	$14.24
Total:				$22.67

2.3.6

Encoder:

- Bore size – ¼ inch
- Input voltage – 5V
- Accuracy within .017° mechanical or 1 arc-minute
- Max frequency – 1MHz

*Refer to Model 15T/H in Encoder section of datasheets

Motor:

- Step angle – 1.8°
- Step angle accuracy – ±5%
- High torque – 380 oz-in
- Shaft diameter – ¼ inch
- Unipolar current – 1Amp per Phase
- 4 Phases

*Refer to Model 23Y Series in Motor section of datasheets

Motorcontrollers:

- Supply voltage DC – 24V
- Max motor current – 7Amps
- Signal voltage DC – 3.3 to 5 Volts

*Refer to Gecko Motor Controllers G210X in Motorcontroller section of datasheets

Microcontrollers:

- Operating voltage range of 2.3V – 3.6V
- 16K-128K SRAM memory
- High speed I/O pins capable of 80MHz
- Minimum of 10 server ports

*Refer to PIC32MX795F512L in Microcontroller section of datasheets

LED:

- Wavelength range – 2600K to 3700K
- Minimum luminous flux – 280 Im at 350 mA
- Color – Warm white
- Max Voltage – 5V

*Refer to Cree White XLAMP MCE LED WT 430 LM in LED section of datasheets

Power Supply:

- Input voltage – 120V
- Output voltage – 24V
- Max amps – 8Amps

2.3.8

Formula we used to determine the speed of the scanning process of each plate:

- $125{,}000\,pix\left(\frac{1\mu m}{1pix}\right)\left(\frac{1step}{5\mu m}\right)\left(\frac{1\sec}{200steps}\right)\left(\frac{1\min}{60\sec}\right) = 2.08\min$

From the formula above we decided that we will use a one-to-one gear ratio to move the *x,y* table the five micron precision that is needed.

Using 125,000 pixels was based on using a slide that was the size of a 3x5 note card.

(1sec/200 steps) is equivalent to one revolution per second.

During the testing of our subcomponents we found that our motor is capable of running at an adequate speed of one revolution per second which will allow for our quick overall scanning time. We also confirmed that our encoder is accurate enough for micron precision that is required. The LED we found produced an ample amount of light which will be great for the receiving the data from the plates as they are being scanned.

2.3.9

When beginning "The Testing Phase," we will begin with writing our final code for our microcontroller. After writing our code we will begin testing the whole system by breadboarding all the subcomponents together and testing the codes compatibility to the system before actually mounting the system onto the mini GAMMA. Then we will test the motor controllers to test its compatibility with the motor and also to test the current output of the controllers. We will then test the LED circuit since it is separate from the system. After testing the system as a whole, we will debug any errors encountered, both in software and hardware.

After the whole system is mounted and wired to the mini GAMMA we will test that the *x-y* table moves correctly. Then we will test that the distance entered into the software equals the output of the encoder which correlates to the distance traveled of the *x-y* table. If there are any errors with table movement precision or output from the software, we will then debug as necessary and retest.

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